European Gas Oil Markets:
Price Relationships, Hedging and Efficiency

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TABLE OF CONTENTS

TABLES

FIGURES

1 INTRODUCTION

The structure of markets is often taken for granted. Companies trade in a commodity market because it exists and do not feel the need to enquire into its origins. But markets are not static entities and, in the case of the oil industry, they are in a constant state of evolution as new trading techniques and new institutions are borrowed or created to satisfy the demands of the wide range of companies that now trade oil. And changes in market structure and performance can have important implications for the trading results of those involved.

The motivation for this study derives from changes in the structure of one market. Over the last five years the bulk market for gas oil in Europe has developed an elaborate structure. It now offers the enterprising trader an array of different trading instruments: some spot, some forward, some futures, and, more recently, options. To have so many markets for what appears to be the same commodity is unusual and raises a number of interesting questions about the behaviour of gas oil prices in the European market. But the answers have a wider significance since they offer insights into the general behaviour of commodity market prices.

The fundamental question is one of differentiation. The fact that there are a number of alternative spot, forward, and futures markets for gas oil suggests that there are differences in price behaviour which are not predictable. If gas oil were a homogeneous commodity it is difficult to see why there should be so many different trading instruments. In these circumstances a single forward or futures market should be enough to satisfy the requirements of all participants. But this is not the case, and each grade of gas oil in the spot market has developed its own forward or futures dimension.

What do we mean by differentiation?

Economic theory makes a distinction between differentiated and homogeneous products (Monke & Petzel, 1984). Homogenous commodities "obey the law of one price" and can be treated as if they are statistically identical since the prices of the different varieties should not exceed the cost of arbitrage. But differentiated commodities require more careful analysis since it is the nature of the differentiation that matters. Prices may not be statistically identical, but they may be statistically dependent. If one price can be predicted from another then the differentiated commodities belong to what is known as an integrated market and can be treated as if they are homogeneous since arbitrage will ensure that the various markets stay in line with each other. Alternatively, prices may be statistically independent in which case each market has a separate purpose since arbitrage will not keep prices in line.

What are the implications of differentiation?

Differentiation raises the question of market performance and pricing efficiency. In an efficient market prices should only change as a result of new information and this should be immediately reflected in current prices (Fama, 1965). Prices therefore follow a random walk and it is not possible to make a profit from trading rules that predict the future behaviour of prices. It follows therefore, that the prices of a homogeneous commodity, or differentiated commodities in an integrated market, cannot both be efficient since one price may be used to forecast another (Granger & Escribano, 1988). In these circumstances there can only be one centre of price discovery since all other prices will depend on that one price. But prices of truly differentiated products will each represent a centre of price discovery since the information that affects prices will be different in each case.

Differentiation is also important from another, more practical, point of view. The concept of hedging depends on the assumption that prices in the futures market move in parallel with the underlying spot market. Thus companies which buy or sell futures contracts against the sale or purchase of the physical commodity are able to "insure" themselves against the consequences of a rise or fall in spot prices since losses on the spot position will be entirely offset by gains on the futures position. But parallel movements require prices in the spot market to maintain a constant differential to prices in the futures market. And any deviation from that simple relationship will affect the value of the hedge. Differentiation will therefore affect the hedging efficiency of the forward and futures markets and could explain the existence of a number of alternative trading instruments.

Another reason for the diversity of markets could be institutional. Forward and futures markets have both substitutable and complementary characteristics. Futures markets have been slow to gain acceptance in the European oil market. In the past the International Petroleum Exchange has found it difficult to attract interest away from the existing informal forward markets that many of the larger oil companies and traders prefer to use. And, until recently, the forward market for Russian gas oil, sometimes known as "Russian Roulette", and the second IPE gas oil futures contract have operated in parallel. Each market had its champions and both displayed a healthy growth in trading volumes. But now the mood has changed and the IPE futures market plays a key role in the gas oil market providing a universal reference for trading in the associated spot and forward markets.

Nevertheless the market has continued to diversify. Although the Russian market peaked in 1988 and much of the activity has since been transferred to the IPE, the forward market is still operating. And an alternative forward market has started trading EEC-qualified gas oil for delivery into Northern France. Both these developments suggest that there is a complementary role for the forward markets despite the dominance of the IPE. At the same time the Rotterdam Energy Futures Exchange (ROEFEX) has launched a new gas oil futures contract using a slightly different specification to the IPE in the hope of benefiting from the new popularity of futures markets.

This study concentrates on three complementary aspects of market function. First, it examines the relative price behaviour of the different trading instruments in order to assess whether there is any evidence for differentiated markets, and, if so, what the nature of the differentiation is. Secondly, it investigates the pricing behaviour of the spot, forward, and futures markets in order to establish whether they are independent random walks or whether they belong to an integrated market with only one centre of price discovery. And thirdly, it evaluates the hedging efficiency of the forward and futures markets in order to discover whether there are significant differences in the value of each as a hedging instrument in the various markets and, if so, why these might arise.

The study uses advanced econometric techniques to study the related issues of pricing efficiency and hedge efficiency. Both make use of daily price data, which poses severe statistical problems for conventional econometric methods since the characteristics of the data violate the basic assumptions of techniques such as ordinary least squares. But, unlike many other studies, which attempt to force the data into the mould required for conventional methods, this study attempts to preserve the awkward characteristics of the data since these provide interesting insights into the process of price discovery. Thus the investigation into price efficiency tests for "unit roots" and employs "Granger" causality tests to identify leads and lags in price relationships between the spot, forward and futures markets in an attempt to find the centre of price discovery in the gas oil market. And, the evaluation of hedge efficiency makes use of "co-integrating" regressions to obtain unbiased estimates of hedge ratios and hedging efficiency for the forward and futures markets. Neither of these relatively new techniques appears to have been used in this context before, and it is hoped that they will contribute to a better understanding of the behaviour of oil market prices.

2 THE MARKETS FOR GAS OIL IN NORTH-WEST EUROPE

Gas oil is the most actively traded petroleum product in Europe. At the consumer end of the market it is sold as two separate products, automotive diesel and light heating oil, differentiated both by quality and price. But to the refiner it is effectively the same product, manufactured from the same cut of the barrel and sharing many of the same qualities. The real difference is fiscal, arising from the fact that automotive gas oil is a substitute for gasoline and therefore often subject to the same level of taxation. In the bulk markets that operate between refiners, traders and wholesalers this distinction does not arise and gas oil is widely traded without specific reference to its final use.

2.1 Market Structure

Despite its fungibility on the demand side, the bulk gas oil market in Europe has developed an elaborate structure involving several distinct varieties of the spot commodity each with its own set of forward or futures markets (see Appendix 1 for a discussion of sources of price information). These distinctions are the result of the interaction of supply side factors such as origin, parcel size, and quality which provide the basis for a differentiated market.

Origin is the most important of these factors because Europe is a net importer of gas oil and the main source is the Soviet Union. Imports from the Soviet Union, unlike those from other EEC countries or certain North African and Middle Eastern countries, are subject to an import tax[1] of 3.5 per cent of the c.i.f. landed value. Parcel size is significant because it distinguishes the import market, which trades cargoes (typically 20,000 tonnes), from the inland and inter-refinery market, which trades barges (typically 1000 tonnes). And quality is important because the Soviet gas oil imports are typically of a higher quality than the standard EEC heating oil grade that forms the basis of the barge and EEC cargo market.

Taken together these three factors determine the structure of the spot market for gas oil in North West Europe which trades c.i.f. non-EEC cargoes imported from the Soviet Union, c.i.f. and f.o.b. EEC cargoes imported from (or exported to) other EEC or suitably qualified countries, and f.o.b. barges for inter-refinery transfers or movements into the inland markets. The spot market is based on the Amsterdam-Rotterdam-Antwerp (ARA) area which acts both as a classical entrepôt, breaking bulk from imported cargoes for trans-shipment up the Rhine into Germany or Switzerland, and as a major swing refining centre processing crude to meet product

[1] There are various ways of avoiding duty on non-EEC qualified imports which have been used in the past. Some of these are no longer possible as the customs authorities in the Netherlands have tightened the rules governing the classification of feedstocks (which are duty free) and outlawed processes such as "stabilisation" and vacuum flashing which used to avoid duty. However, duty credits arising from exports to non-EEC countries such as Sweden and Switzerland are still available to refiners. It also now seems likely that at least some of the gas oil imports from the Soviet Union will be subject to a duty free quota. If this is extended to cover the majority of imports this distinction may cease to be important.

demand wherever and whenever it arises. But as will be shown later, prices in the three major spot markets for gas oil do not always move together and there are frequent opportunities for arbitrage between them.

Spot trading has a long history in Europe dating back to the early 1960s, but during the 1980s there has been an explosion in activity. Spot markets have moved from the periphery to the centre of the oil business as their function has changed from simply balancing the surpluses and deficits of the integrated oil companies to become the primary pricing mechanism for all oil trade. Associated with the growth of spot oil trading has been the development of new trading instruments such as forward and futures markets which have further expanded both the volume of trading and the range of market participants. As a result, each of the three major spot gas oil markets identified above now has its own associated forward or futures market which allows traders to hedge positions in the spot market, to speculate on the future outcome of prices and, most importantly, to extend the scope of arbitrage.

Forward trading of refined products in Europe began with gas oil, but has now extended to naphtha and residual fuel oil. The first forward market to get off the ground was based on non-EEC gas oil. Also known as "Russian Roulette", it began trading on a small scale in the early 1980s when a number of companies that held term contracts with the Soviet oil export agency, Soyuzneftеksport, started to buy and sell between themselves paper claims to cargoes of Russian gas oil for future delivery into North West Europe. This development mirrored the introduction of forward trading in 15-Day Brent to the crude oil market and can be seen as a response by some members of the European oil industry to the successful launch of the New York Mercantile Exchange heating oil futures contract in the United States.

The development of the forward market in Russian gas oil was helped by the terms under which the Soviet Union chose to market its oil products.[2] Unlike many other oil-exporting countries at that time the Soviet Union continued to sell the majority of its oil product exports under term contracts. The structure of the contracts was, however, slightly unusual since Soyuzneftеksport retained the right to decide on the timing of cargoes supplied under what are known as "framework contracts". So in order to make the contracts attractive and to ensure offtake a market-related formula was used to establish the price of each cargo. This was necessary because the Soviet Union is heavily dependent on oil exports as a source of hard currency.

In the case of gas oil the formula was initially based on the mean of the means of Platt's cargoes c.i.f. and Platt's barges f.o.b. Rotterdam on the date of the bill of lading with adjustments for variations in quality or delivery terms. Many of the original contract holders were trading companies which supplied the Rhine barge market together with a few of the major European refining companies. Soviet gas oil exports thus found their way into the hands of fifteen to twenty middlemen who had a mutual interest in hedging the price and volume risks inherent in the term contract and speculating over the future

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2 For a fuller discussion of these issues see Long, *Soviet Oil Exports and Marketing Strategies* in Chadwick, Long and Nissanke, 1987.

course of oil prices.

Price risks arise from the delay between the bill of lading formula and the arrival of the cargo in Rotterdam. And volume risks arise because the seller, Soyuznefteksport, nominates the loading date for the cargo which makes it difficult for a buyer to sell a physical cargo forward with any degree of confidence. Participants in the forward market for Russian gas oil therefore trade substitute "paper" cargoes against the eventual delivery of physical oil for delivery c.i.f. North West Europe up to three or four months ahead.

At about the same time, in April 1981, the London International Petroleum Exchange (IPE) launched their first futures contract based on delivery ex-tank at Rotterdam. In retrospect this appears to have been a mistake since the contract was not based on an existing spot market and performed relatively poorly as a result. It also failed to meet the key quality standards demanded by the Federal Republic of Germany. The IPE gas oil futures contract was re-launched in November 1984 and has been much more successful since then overtaking the Russian forward market as the most active contract during 1988. The revised "Number 2" contract is based on the spot barge market and trades 100 tonne lots for delivery f.o.b. ARA up to eight or nine months ahead.

Recently two new gas oil contracts have been created. Towards the end of 1988 a new forward market - the so-called "French flexi market" - sprang up trading cargo parcels of EEC gas oil for delivery c.i.f. Le Havre over a period of three to four months ahead. And now the Rotterdam Energy Futures Exchange (ROEFEX) has launched another gas oil futures contract based on the ARA barge market. Whether these can both succeed in addition to the existing forward Russian and IPE futures contract remains to be seen.

2.2 Forward and Futures Contracts

Forward and futures markets in oil have evolved to perform many of the same functions. They both provide a standardized trading instrument which can be bought and sold for future delivery at a relatively low cost. Such instruments allow participants either to hedge existing physical positions with an offsetting purchase or sale in the forward or futures market, or to speculate on the future course of prices by taking a long or short position. Since the key features of the contract, such as quality and delivery terms, are standardized, negotiation between participants is limited to price which both simplifies and encourages trading. It also improves price transparency for participants in the market since transactions may be compared without difficulty. Both of these features of forward and futures contracts promote liquidity which is essential for the effective operation of any market.

The use of standardized contracts has allowed forward markets in oil to attain a level of activity and sophistication not normally found in commodity markets outside an organized futures exchange or clearing house. Only the foreign exchange markets appear to have developed forward trading to the same degree. Forward contracts are widely used in other commodity markets, but they are typically "tailor-made" contracts which are costly to negotiate and unsuitable for any kind of speculative activity. Forward contracting therefore plays a complementary role to the futures market which remains the primary medium for setting prices. In the case of oil, however, forward markets such as the 15-Day Brent market are used as substitutes for futures markets competing for the interest of traders and playing a key role in the process of setting prices.

The fact that Russian gas oil exports are usually of a uniform quality and are typically shipped in 38,000 tonne parcels in Soviet flag vessels meant that the key trading characteristics of these "paper" cargoes became standardized early on in the life of the market, allowing it to expand quickly from a conventional forward market into something more like a futures market. The initial terms and conditions adopted by the market for paper contracts specified that the seller will deliver 18-25,000 tonnes of Russian gas oil c.i.f. ARA during either the first half (1-15) or second half (16-31) of the month. In addition, sellers are obliged to give two clear working days notice of the arrival of a cargo which is to be nominated against a paper contract, and only cargoes which originated in the Soviet Union and meet the minimum standards defined in the contract can be nominated.

Since then very few changes have been made to these rather simple terms and conditions despite the efforts of some participants to devise a more comprehensive contract. The upper limit on the contract was reduced to 22,000 tonnes during 1987 in order to make it easier to split Russian shipments into two parcels. And up to about the middle of 1986 forward trading took place over a four-to-eight week horizon, i.e. one-to-three delivery periods ahead, but from 1987 onwards the trading horizon moved further forward and the second half of the month became less popular as a delivery option at about the same time leaving the market focused on first half delivery.

There are, however, some important differences in the nature of forward and futures markets which are often forgotten when these markets operate smoothly. First, there is the type of contract. A forward contract, even when it is standardized as it is in the case of oil markets, remains a private contract between two companies. Like all contracts it depends on the good faith of both parties for its success. But a futures contract is guaranteed by the exchange which acts as the counterpart to all futures transactions. Forward contracts therefore carry an additional risk of default which does not arise in the case of futures.

Secondly, there is the method of clearing the market. Forward contracts cannot be cleared in advance of their delivery date[3] and carry a firm obligation to deliver the

[3] The use of a standardized contract allows participants to buy and sell many more paper contracts than they expect to receive physical cargoes since one physical cargo can be used to satisfy more than one paper contract as long as all the buyers do not wish to take delivery. Thus trading in Russian gas oil creates a backlog of paper contracts for each half-month delivery period that needs to be cleared if the smaller number of physical cargoes supplied by Soyuzneftеksport are to be matched to the greater number of paper claims. But because trading takes place directly between the participants and there is no formal exchange or clearing house to organize the discharge of the backlog of paper contracts for each delivery period, this is done by the participants themselves with the assistance of specialist brokers who service the market.

The method adopted can only be described as haphazard. Since a a paper contract can only be discharged once a physical cargo has been nominated against it, every seller must be in a position to nominate a cargo. Cargoes are therefore passed from seller to buyer (as long as adequate notice can be given) creating a "daisy physical oil if called upon to do so. Thus it is possible that transactions which appear to offset each other, for example a purchase and sale for delivery in the same contract month, will both require physical oil at different dates. Futures markets are cleared every day by the exchange which matches buyers and sellers and offsetting transactions can always be completed in advance of the delivery month and without the need for physical oil. Forward markets therefore carry an additional delivery risk that does not arise in the case of futures.

Thirdly, there is price transparency. Forward contracts are agreed privately between participants, usually over the telephone. There is no obligation to report such transactions and so information circulating in the market is necessarily incomplete and may be out of date or inaccurate. Futures contracts are negotiated in public on the floor of the exchange and all transactions are reported and widely disseminated by the exchange. Price information is therefore complete, immediate, and accurate.

Finally, there are the costs of trading. Forward contracts involve few direct costs. Large participants with a good credit rating are usually able to trade without a letter of credit and so need not incur any charge until the date of delivery. Futures contracts can be more expensive. Any futures transaction requires a margin as a guarantee of good faith, although it is usually possible to fulfil margin requirements with an interest bearing instrument which minimizes the cost. And any subsequent losses on the contract must be paid to the exchange each day or the position will be closed out. In addition, trading on a futures exchange must be conducted through a registered broker who will also charge a small fee for each transaction. Although these fees may be very low for a large customer it still represents an additional charge which large players need not incur on an unregulated forward market.

In other commodity markets, for example the grain market complex in the mid-western United States, forward markets have acted as a precursor to the development of futures markets. In fact there are striking similarities between the operation of the Russian

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chain" of paper contracts linking the original seller who holds the cargo to the ultimate buyer who takes delivery. This potentially slow process can be speeded up where a "circle" of contracts can be identified in advance of the delivery period which link a buy and a sell by the same participant. In this case the companies involved can agree to "book out" the paper contracts settling their obligations by paying a differential rather than the absolute price of the contract. This has the advantage of cutting down the backlog of contracts once the delivery period opens, but it can only work if all the participants agree to a "bookout". The same method is also used in other oil forward markets such as the 15-Day Brent market. One important difference, however, between an f.o.b. market such as Brent and a c.i.f. market such as Russian gas oil, is that the same cargo can be rolled forward from one delivery period to the next in order to "wet" another chain as long as the costs of delaying the vessel do not exceed the benefits.

Various attempts have been made to streamline the market clearing process since it is not only cumbersome but also open to abuse if the number of Soviet shipments is smaller than expected and the paper backlog large. In these circumstances participants holding physical cargoes can demand a substantial premium from those who are obliged to buy from them in order to fulfil their contractual obligations. In order to avoid "squeezes" of this type some participants have proposed that "bookouts" should become mandatory, while others have suggested that a clearing house should be established. Neither has been accepted as yet and the risk of squeezes remains with the market.

forward market and the early days of the Chicago grain market at the end of the last century, described by Jeffrey Williams (pp. 4-10) in his stimulating book *The Economic Function of Futures Markets*. Burns (1983, p.52) suggests that one could simply "view futures as the application of economies of scale to forward contracts". However, evolution is not inevitable as the persistence of forward markets for foreign exchange and the development of the London Metal Exchange as a clearing-house for forward metal trading indicate (Goss, 1986, p.157ff). Different industries prefer different institutions and it may be that the oil industry can combine its traditional preference for dealing face to face (Long, 1987, p.205) with the need for a transparent and efficient pricing medium by combining the merits of the two types of market in a hybrid structure of forward and futures.

2.3 Price Relationships

The existence of several markets for the same product at the same location poses an obvious, but important, question: what are the differences in price behaviour between each market? According to economic theory there should be no exploitable relationships between prices in an efficient market. On the one hand, this implies that price differences should be random since it should not be possible to forecast one price from another (Granger and Escribano, 1988). But, on the other hand, it suggests that price differences between substitutable commodities should not exceed the cost of arbitrage. In this case price differences between the spot, forward, and futures markets for gas oil should reflect differences in contract specification.

(a) Contract Specifications. The specifications of three spot gas oil assessments published by Petroleum Argus include a number of factors that might lead to differentiated markets.

First, there may be differences due to quality. Russian gas oil has a lower specific gravity than the heating grade standard (0.836 compared with 0.845) which provides the basis for the f.o.b. barge and c.i.f. EEC cargo assessments. The lower gravity is an advantage for companies selling into the inland market where quantities are measured by volume rather than by weight. Also, although the maximum sulphur limits for Russian cargoes have always matched EEC standards, Russian cargoes are often of better quality and this perception may also influence relative prices.

Secondly, there may be differences due to timing. Spot barge assessments are based on lifting/delivery 2-12 days forward compared with 5-20 days for the cargo market assessments. The relationship between barge and cargo assessments may therefore be affected by the premium (or discount) for prompt delivery.[4]

Thirdly, there may be differences due to parcel size. The cargo market trades parcels of 18,000-25,000 tonnes while the barge market trades parcels of 1,000-2,000 tonnes. And factors such as the cost of breaking bulk from imported cargoes to barges and the convenience value of smaller quantities may play a role.

[4] I am grateful to Walter Greaves of Czarnikow Energy for this suggestion.

Finally, there may be differences arising from import duties: c.i.f. non-EEC gas oil cargoes are of Russian origin and potentially subject to EEC import duty of 3.5 per cent of the c.i.f. landed value. But, as we have seen above, there are loopholes in the legislation that allow some companies to avoid paying duty and so this may not be important.

Forward and futures prices for gas oil may also be differentiated for similar reasons since the underlying spot commodity is not the same for each market. The forward Russian market is based on delivery of a Russian (i.e. non-EEC) cargo c.i.f. ARA, while the IPE gas oil futures market is based on delivery of EEC gas oil into the f.o.b. barge market. Thus any quality differentials that apply in the spot market may also apply in the forward and futures market.

There are also important differences in the operation of the two types of market which may lead to differences in prices. Forward and futures markets have different payment schedules which can generate different present values for forward and futures contracts for identical commodities (Black, 1976). Futures contracts are marked to market each day and the resultant profit or loss is either credited to or deducted from the initial deposit made by the purchaser or seller of the contract. And any losses must be made good by the contract holder. Forward contracts, on the other hand, are not marked to market and any changes in the value of the contract are accumulated and settled when the contract is discharged.

This argument was elaborated by Cox, Ingersoll and Ross (1981) to take account of variations in short-term interest rates. Their paper does not, however, provide a clear prediction of whether forward prices should be at a discount or a premium to futures prices. But empirical work in other financial and commodity markets has shown that forward prices tend to exceed futures prices and that the differences increase with time to maturity.

Finally, forward and futures prices are usually expected to trade at a differential to spot market prices and this is likely to affect the relationship between prices in the two types of market. Once again economic theory does not provide a clear prediction of either the size or the sign of the premium. Keynes (1927) argued that futures prices would normally tend to be at a discount to spot or cash prices because the net hedging interest (or "pressure") in a typical futures market came from companies that were long in the physical market, for example producers or middle-men, who needed to sell futures contracts in order to buy insurance. The balance of the price risk was borne by "speculators" who had no offsetting sales in the physical market against which to purchase futures contracts. Thus futures prices would need to be below spot prices in order to ensure that speculators receive a premium for shouldering the price risk. In British financial markets this situation is known as "backwardation" and so Keynes' description, which was later restated and expanded by Hicks (1946) is known as the "normal backwardation" hypothesis.

Other economists have disputed the Keynes-Hicks view of futures markets from a variety of viewpoints (see Kamara, 1982, pp.270-275). Some argue that the net hedging pressure is from the short side of the market. In other words end-users, rather than producers or middle-men, dominate the market leading to more net purchases than sales of futures contracts. The same arguments apply as in the Keynes-Hicks case, but futures prices must be above spot prices if the speculators are to receive a premium. This is known as "contango" in British financial markets. Others argue, however, that there is no necessary bias in futures markets prices since the net hedging pressure will depend on the forces of supply and demand in the underlying market. Thus buying pressure will lead to backwardation while selling pressure will lead to contango.

In empirical terms, however, there is no strong evidence for either the Keynes-Hicks view, which implies an upward bias (i.e. a positive mean) in futures price changes, or its alternative formulation, which implies a downward bias (or negative mean). Extensive studies of the behaviour of returns in financial and commodity markets have shown that mean returns over long periods of time are rarely significantly different from zero. Nor is there any strong evidence that the spread between spot and futures prices is either persistently negative or positive as is implied by the two versions of the theory. In fact, the only strong evidence of a relationship between backwardation and contango in futures markets and net hedging pressure comes from the pioneering studies of the relationship between stock levels and spreads conducted by Holbrook Working who found that periods of backwardation in grain futures markets are associated with low grain stocks and periods of contango with high grain stocks (Working, 1948, 1949).

In Working's view, price insurance is only one of several possible motives for hedging, and so it would be wrong to expect that the relationship between spot and futures prices for any commodity is determined solely by the interaction between passive risk averse "hedgers" and active risk bearing speculators. Hedging is a much more complex process which involves decisions about the proportion of stocks to be hedged, expectations about the future level of prices, and which enables companies to take advantage of favourable movements in the basis between spot and futures prices, as well as providing a measure of price insurance. "Most hedging", he suggests, "is done in expectation of a change in spot-futures price relations" (Working, 1953). In other words hedgers and speculators can only be distinguished by their underlying position on the physical market and not their trading behaviour on the futures market.

(b) Price Differentials and Price Ratios. Do any of these differences in contract specification lead to statistically significant differences in price behaviour? In the long run, as can be seen from Figure 2.1, spot, forward and futures prices in the gas oil market in North West Europe have followed a very similar path and it is often difficult to distinguish one from the other. Spot prices in the f.o.b. barge, c.i.f. EEC and c.i.f. non-EEC cargo market moved closely together before the introduction of the second IPE gas oil contract in 1985, and the addition of the new forward and futures trading instruments has not disturbed this general pattern of behaviour. Furthermore simple statistics indicate that there are no significant differences in the average level of spot prices over a six-year period from 1983-88, or the average level of forward, futures and spot prices over a four-year period from 1985-88. The mean price differential between any pair of prices is not significantly different from zero, and the mean price ratio is not significantly different from unity.

But this is not to say that there are no differences in price behaviour during the period.

In fact both price differentials and price ratios between all the pairs of markets are highly variable in the short run. For example, the price differential between barges and non-EEC cargoes ranged between a discount of \$10.50/tonne and a premium of \$32/tonne, and the price ratio ranged between 0.928 and 1.198 during a six-year period from 1983. Similarly the price differential between barges and first month IPE gas oil ranged between a premium of \$14.00/tonne and a discount of \$1.50/tonne, and the price ratio ranged between 0.994 and 1.061 over a four-year period from 1985. Although these are extreme values, the size of the standard deviations shown in Table 2.1 for both the differentials and the ratios indicates that these frequently move over a wide range. And, in statistical terms it is the variability of the differentials and ratios which determines whether they are significantly different from zero or unity. It is therefore possible that the high degree of variability is obscuring any underlying price differences that might exist in the market.

It is also possible that the relationships have changed over time. For example, the introduction of forward and futures markets may have had an effect on spot prices. But, if the sample is split into two parts, before and after the introduction of the successful IPE gas oil contract, similar results are obtained for all pairs of markets except for EEC and non-EEC cargoes. In this case both the differential and the ratio are significant in the pre-IPE2 period suggesting that the relationship between the two markets was more stable in 1983 and 1984. Interestingly the ratio is 1.019, indicating that the average level of EEC cargo prices is about 2 per cent higher than non-EEC cargo prices. This compares with EEC import duty of 3.5 per cent of the c.i.f. landed value. The mean ratio is the same for the IPE2 period from 1985 to 1988, but the standard deviation is about double, indicating a more unstable relationship which is not statistically different from zero.

Finally, breaking the period down into annual sub-samples reveals that the larger standard deviations observed across all pairs of markets for the IPE2 period are confined to 1986, the year of the price collapse. But even when this year is excluded from the sample no new statistically significant price differentials or ratios emerge.

(c) Seasonal Patterns. One explanation for the variation in price differentials and ratios could be seasonality. The demand for gas oil is strongly influenced by winter heating oil consumption and this may be reflected in the price behaviour. As can be seen from Figure 2.2, the seasonal patterns in the **spot** price ratios are very distinctive, and differ from market to market.

The seasonal pattern in the ratio between the two pairs of cargo market prices, EEC and non-EEC cargoes, is highest in the winter (December/January) and lowest in the summer (June/July), and moves fairly smoothly from peak to trough through the year. The winter peak is around 1.03 or 3 per cent, just below the EEC import duty mark-up of 3.5 per cent, and the summer trough is around 1.01 or 1 per cent. Since non-EEC cargoes are of a better quality than EEC cargoes, it is reasonable to expect that the duty mark-up will be less than the full 3.5 per cent. But the seasonal pattern does appear to indicate that either the quality premium is worth substantially more in the summer (low gravity blending components may have a higher value when gasoline is in demand), or it is easier to avoid paying import duty during the summer months when the volume of imports is lower and companies have offsets or spare processing capacity available.

The seasonal pattern in the ratio between the barge and non-EEC cargo market is quite different. It is highest in the spring (March/April) and lowest in the autumn (October/November). It also moves fairly smoothly from peak to trough, the spring peak being around 1.025 (2.5 per cent) and the autumn trough around parity. Interestingly this is the inverse of the seasonal stockholding pattern for gas oil stocks in the ARA region reported by Petroleum Argus (see Figure 2.3). In other words the barge premium over non-EEC cargoes is at its highest when the stocks are lowest in the spring, and at its lowest when the stocks are highest in the autumn - an observation which supports the idea that there may be a time dimension to the barges:non-EEC cargo price relationship.

The seasonal pattern in the ratio between barges and EEC cargoes appears to be a mixture of the other two patterns. As with the non-EEC cargo market, the barge:EEC cargo ratio is higher in the spring than in the autumn, although this time the ratio moves from around parity in the spring to a discount in the autumn. In addition the spring peak is stretched into the summer.

Turning now to the forward and futures markets, it appears that while seasonality does not play a role in the relationship between forward and futures prices, it is very important in the relationship between forward and spot, and futures and spot prices.

The seasonal pattern for the spot:forward and spot:futures price ratios is highest in the spring (April) and lowest in the late summer and early autumn (August - October), see Figure 2.4. The transition from peak to trough is not as smooth as it is in the spot market since there is an additional peak in December in both markets, but otherwise the pattern is very similar to that observed for the barge:non-EEC cargo price ratio. In fact the correspondence between the ARA stockholding pattern in Figure 2.3 and the spot:forward and spot:futures price ratios is even more striking since the end-year effect is also present in the gas oil stocks.

But the most interesting result is obtained from comparing the seasonal pattern for the spot:forward price ratio with the seasonal pattern for the spot:futures price ratio. As can be seen from Figure 2.4, the shape of the pattern is very similar for the two pairs of markets, but the spring peak is much higher for the spot:futures ratio than the spot:forward ratio. The spot:forward peak is 1.015 (1.5 per cent) while the spot:futures peak is 1.03 (3 per cent). The higher peak for the spot:futures ratio reflects the difference in the underlying spot markets, f.o.b. barges for futures and non-EEC cargoes for the forward market. Thus although the forward and futures markets have similar delivery horizons, and appear to be used as interchangeable trading instruments, the underlying spot markets do not have the same delivery horizons and this affects the relative size of the spot:forward and spot:futures differential at times when the premium for prompt delivery is very large.

(d) Tests for Differentiated Prices. A more precise method of evaluating the relationship between the various price series is to carry out a simple regression for each pair of prices, i.e.

$$P1 = a + bP2 + ut$$

where, P1 and P2 are a pair of price series,
a is a constant
b is a ratio, and
ut is the residual error term.

This regression yields five possible results (Monke and Petzel, 1984, pp.482-3). First, if there is no relationship between the two price series, i.e they are randomly distributed relative to each other, the ratio, b, will not be significantly different from zero. This is highly unlikely given the evidence already presented above. Secondly, if prices are statistically identical, the constant will not be significantly different from zero and the ratio will not be significantly different from unity. Thirdly, there might be an absolute premium, for example the cost of breaking bulk, in which case the constant will be significantly different from zero, but the ratio will not be significantly different from unity. Fourthly, there might be a percentage mark-up, for example import duty, in which case the ratio will be significantly different from unity, but the constant will not be significantly different from zero. And finally, there might be a mixture of the two, in which case the constant will be significantly different from zero and the ratio significantly different from unity.

Prices in all the markets are strongly related to each other as can be seen from the regression results in Table 2.2, since the ratio is significantly different from zero in every case. At the same time the three price series do not appear to be to be statistically identical since the constants are all significantly different from zero and the ratios are all significantly different from unity, indicating that the relationship is neither a simple fixed differential nor a simple percentage mark-up. But the results may not be reliable since the Durbin-Watson statistics for all three regressions are less than two, indicating that the residual term is serially correlated. This suggests the presence of a missing explanatory variable or some other systematic process. However, although the Durbin-Watson statistics are small, they are still large enough to indicate a stationary residual term in the case of the barge:non-EEC cargo and EEC:non-EEC cargo regressions (Sargan and Bhargava, 1983). In these cases the regressions should yield reliable parameter estimates (Engle and Granger, 1987), but the confidence limits for the Student's t-test will be higher.[5]

The results of these regressions suggest that some other process affects the relationship between gas oil prices. In the case of the three pairs of spot prices, as can be seen from Figures 2.5, 2.6, and 2.7, price ratios are far from constant, and there seem to be a number of possible explanations for the missing factor (or factors). First, it appears that ratios were abnormally large during the 1986 price collapse. This suggests that the markets may have become temporarily dislocated at that time - which might distort the results of any analysis of relative price behaviour. Secondly, ratios are highly variable in

[5] Engle and Granger (1987) give a critical value of 3.37 at the 5 per cent level for a sample of 100 observations. But this question and other related issues are dealt with in greater detail below, see Chapter 3. Only in the case of the barge:EEC cargo regressions is there evidence of a non-stationary residual term.

the short run, indicating that there are frequent opportunities for arbitrage. Thirdly, there are signs of a longer-run cycle, possibly a seasonal pattern, in the behaviour of price ratios. Finally, although the barge:non-EEC cargo ratio, and the EEC:non-EEC cargo ratios appear to oscillate about a fairly constant mean level, it appears that the mean level of the barge:EEC cargo ratio has shifted between 1983-85 and 1987-88. This shift may explain the very low Durbin-Watson statistic obtained above.

Excluding the effects of the 1986 price collapse from the regressions certainly improves the results in two out of the three cases, but does not solve the problem of serial correlation in the residuals. Including a dummy variable for the period February to May 1986 reduces the standard error of the regression equations for barges and non-EEC cargoes and barges and EEC cargoes, yielding larger Durbin-Watson statistics, but these are still well below the critical value of two. And allowing for seasonal factors also improves the results, but does not succeed in eradicating the problem of serial correlation. But, as can be seen from Table 2.3, combining both sets of dummies in one regression leaves the Durbin-Watson statistics well below two.

Splitting the sample into two parts, the first from 1983-84 (before the new IPE gas oil futures contract) and the second from 1987-1988 (after the 1986 price collapse) yields some interesting results once seasonality has been taken into account. First, the Durbin-Watson statistics indicate stationary residuals for all pairs of price series. This suggests that the barge:non-EEC cargo relationship is stable in both sub-periods, and is consistent with the idea that there may have been a structural shift in the relationship before and after 1986. Secondly, the Durbin-Watson statistic is much higher in the later period than it was in the earlier period for all pairs of price series. This suggests that the level of serial correlation in the residuals fell between 1983-84 and 1987-88, and is consistent with the idea that the introduction and growth of the IPE futures contract has improved market efficiency.

In the case of the forward and futures market prices, the initial degree of serial correlation is not so severe. Furthermore, as can be seen from Figure 2.8, the behaviour of the price ratio between forward and futures prices is rather different from that of the three pairs of spot market prices. Although 1986 also appears to have been a period of greater volatility in the price ratio, there is no evidence of a seasonal pattern, and the short-run volatility seems to have become much less pronounced over the IPE2 period. These observations are supported by the results of further regressions including the 1986 dummy (which was significant) and the eleven seasonal dummies (which were not). And splitting the sample into annual sub-samples confirms that the degree of serial correlation fell between 1985 and 1987-88.

In the case of the forward:spot and futures:spot prices the initial degree of serial correlation was much greater. This is also consistent with the behaviour of the six pairs of forward:spot and futures:spot ratios; not only was 1986 a period of much greater volatility, but also the range of seasonal variation appears to be much greater.

The basis between both the forward Russian market and its underlying spot equivalent, the c.i.f. non-EEC cargoes market, and the IPE gas oil futures contract and its underlying equivalent, the f.o.b. barges market, is far from constant as can be seen from Figures 2.9

and 2.10. Both markets display extended periods of backwardation and contango and the size of the spot premium (or discount) is highly variable. During the first six months of 1986 the spot premium reached over $20/tonne. It is impossible for the basis to reach such extreme values when the market is in contango, unless the cost of storage is very high, as participants will always sell forward and buy physical oil for storage if the spot discount is sufficient to offset the costs of doing this.

Further regressions including the 1986 dummy and the eleven seasonal dummies reveal that both sets of factors are significant, but once again neither is sufficient to remove the signs of serial correlation from the regression results.

Why should there be such strong evidence for serial correlation in these simple regressions? One possibility is that it takes time for arbitrage to occur. In other words the markets are inefficient in the short run. One of the most important functions of a market is to communicate information about prices. And for a market to perform efficiently this must be done accurately and without delay. If prices are not transparent, or if it takes time for new information to be disseminated, participants may find that they are taking decisions based on inaccurate or old information. Inefficiency may therefore lead to less-than-instantaneous adjustments in relative prices and create opportunities for arbitrage. And inefficiency could therefore explain the short-run instability of price ratios and differentials between the spot markets for gas oil in North West Europe.

3 PRICE EFFICIENCY

There is a long tradition of academic literature concerned with testing the pricing efficiency of markets. Most of the research in recent years stems from two seminal papers by Eugene Fama published in 1965 and 1970. Fama himself drew on ideas about the behaviour of prices introduced by a French mathematician, Louis Bachelier, at the turn of the century, and his later paper benefited from the work of Mandelbrot and Samuelson who provided a theoretical framework for what had previously been largely empirical analysis. But Fama's papers represent the first systematic attempt to evaluate pricing efficiency for a major market and provide a basic toolkit of techniques that have been used by many others in the field.

3.1 Efficient Markets Hypothesis

Fama's original (1965) definition of price efficiency is very simple and depends on the way in which markets process information. New information is the driving force behind price changes in any market. If new information is simultaneously available to all participants then it will be instantaneously and fully reflected in price changes. Prices will not change therefore unless new information becomes available. As a result the sequence of price changes will be serially independent. The probability distribution of price changes is not predetermined, but if transactions are fairly uniformly spread over time and the number of transactions per unit of time is very large then price changes should conform to a normal (Gaussian) distribution. This view of price behaviour is diametrically opposed to the one espoused by chartists and others who base their forecasts on the assumption that past behaviour is a guide to the future. In Fama's efficient market prices follow a random walk and past price changes cannot be used to predict the future.

Between 1965 and 1970 Fama's definition of an efficient market became both more elaborate and less restrictive. On the one hand he introduced three levels of market efficiency: the so-called "weak", "semi-strong", and "strong" forms of the efficient markets hypothesis. These are distinguished by the type of information employed in tests of market efficiency. Only past prices are considered in the weak form, while other publicly available information is included in the semi-strong form, and private or insider information is included in the strong form. And, on the other hand, he relaxed the strict requirement that prices should follow a random walk for the less onerous "fair game" or martingale process. Under this assumption it is possible for a sequence of price changes to display a certain amount of dependency as long as the costs of exploiting such dependencies are at least equal to the likely profits.

The weak form of the efficient markets hypothesis thus generates two testable propositions. First, the sequence of price returns should not display exploitable serial dependencies. And, secondly, the distribution of returns should conform to some quantifiable form of probability distribution. Much of the earlier work in this area focused on the extreme case of a random walk in prices (i.e. no serial dependence) and a normal distribution of returns. Both are sufficient to characterize a market as efficient, but as we have seen above, neither is necessary.

It is, of course, easier to test for market efficiency in its extreme form since the results are clear cut, but it is wrong to conclude that a market is seriously inefficient if it fails to match the ideal. Assessing whether serial dependence is exploitable or not is more contentious and the conclusions are likely to be subjective. Similarly deviations from normality in the distribution of returns present a bewildering array of possibilities and can pose severe statistical problems. Nevertheless, tackling these difficulties can provide interesting insights into the operation of markets since it is in these grey areas that one may catch a glimpse of the process of price formation at work.

The general consensus of empirical work (Kamara, 1982, pp. 275-278) in this area is that probably all markets display signs of inefficiency. It is therefore unlikely that the gas oil market in North West Europe will be any different. There are, however, important differences in the behaviour of returns for stock, currency, and commodity markets (see Taylor, 1986, pp. 169-70). Stock market prices which Fama used for his empirical work, are much closer to the ideal of an efficient market than currency and commodity markets. In particular, although they suffer from positive serial correlation (i.e. a tendency for prices to continue to move in the same direction after a price change), the size of the first lag autocorrelation coefficient is small and there is no evidence of longer-term dependency. Thus although it might be possible to develop a trading rule based on this behaviour it is unlikely that it would yield any profits after costs were included. Stock market prices therefore reflect new information fairly quickly although not instantaneously. Currency and commodity market prices, on the other hand, show statistical dependence at several lags indicating that information can take much longer to be fully reflected in prices. As a result it is possible to develop trading rules which generate consistent profits after costs.

Fama's hypothesis is also important for another more practical reason. Over the last ten years economists have become much more interested in the statistical properties of the time series data used to test their hypotheses. In particular they have been obliged to accept that the behaviour of many economic time series, including prices, resembles that of a random walk (Working, 1934 in Hendry, 1986 p. 203). Such series pose problems for the econometrician as they do not conform to the useful properties of the "normal" distribution that underpins the basic regression procedures which are used to test the validity of economic theory.

Ordinary least squares regression itself does not demand the use of normally distributed variables since the procedure involves the estimation of an equation which minimizes the variance of the residual or unexplained errors. This only requires that the residual term should have a zero mean, constant variance and zero covariance, all of which are properties of the normal distribution but not properties that are exclusive to it. But normality becomes important for testing the statistical significance of the estimated parameters (Johnston, 1984, pp.32-33). Standard methods, such as Student's t-test, employ confidence limits that depend on the assumption that the residual term conforms to a normal distribution, and can give misleading results if it does not. One of the most useful properties of the normal distribution is that linear combinations of normal distributions will also yield a normal distribution. And it is for this reason that econometricians prefer to use normally distributed variables in ordinary least squares regressions since this ensures that the residual term will also be normally distributed.

In the past, econometricians have usually differenced their data to remove random walk and trendlike components and obtain approximately normally distributed variables. But simple differencing may not always be appropriate since it may obscure important long-run information in the data (Hendry, 1986, p.201). Furthermore mechanical pre-processing of data in this fashion creates a serious risk of spurious results since the conventional test statistics can be misleading and the estimated parameters may be biased because differencing may not always achieve the desired result. In order to deal with these problems a new approach to econometrics has been developed which takes account of the awkward properties of economic time series data and provides a powerful tool for analysing the behaviour of commodity market prices.

The new approach to econometrics begins with the characteristics of the generating mechanism for the series since this will determine the appropriate functional form for any model that is to be tested. And the most important of these characteristics is what is known as the "order of integration" (Granger, 1981 in Hendry, 1986 p. 202). Any stationary series, such as one which conforms to a normal distribution, is described as being "integrated of order zero" or I(0) since no differencing is necessary to obtain a series with time-invariant linear properties. The definition of an I(0) series is in fact wider than this (Granger, 1986, p. 214), but this is a convenient simplification (Hendry, 1986, p. 202). Any series, such as a random walk, which needs to be differenced once to achieve these properties is therefore described as I(1) - "integrated of order one" - and a series which needs to be differenced twice is described as I(2) and so on. It appears that many economic time series are probably I(1).

In theory, there are substantial differences between the characteristics of an I(0) and an I(1) series (Granger, 1986, p. 214). An I(0) series tends to fluctuate about its mean and has a finite memory since autocorrelations decline rapidly as the lag increases. Hence the effects of any innovation are only temporary. By contrast, an I(1) series will rarely (if ever) return to its initial value and has an infinite memory since autocorrelations remain large at long lags. The effects of any innovation are therefore permanent. But, in practice, the distinction is not always easy to make since an I(0) series can appear to be very similar to an I(1) series. The distinction is, however, very important since linear combinations of I(0) and I(1) series in a least squares regression will generate an I(1) error term which does not satisfy the requirements outlined above and may therefore lead to spurious conclusions. As a result a considerable amount of effort has been devoted by statisticians in recent years to finding tests which are able to distinguish reliably between an I(0) and an I(1) series (Granger and Engle, 1987).

The problem of distinguishing between the two types of behaviour is best explained by comparing the characteristics of a stationary autoregressive series, which is I(0), with those of a random walk, which is I(1). The only difference between a stationary autoregressive series, for example

$$x_t = ax_{t-1} + e_t$$

where, $|a| < 1$ and e_t is white noise, and a random walk, i.e.

$$x_t = x_{t-1} + e_t$$

is that the coefficient on x_{t-1} or "root" of the process is unity in the case of a random walk and less than unity in the case of a stationary autoregressive process. Thus the behaviour of the time series will become progressively more like a random walk as the root tends towards unity and more like white noise as it tends towards zero. And it becomes increasingly difficult to tell the difference as the root approaches unity.

Testing for "unit roots" has therefore become an important pre-cursor to the analysis of economic time series data since this enables the econometrician to establish the order of integration of each series that is incorporated into a model. It is particularly important in the case of series of financial or commodity prices since these are expected to conform to a random walk if markets are efficient in the manner suggested by Fama. Such tests can be performed using least squares regression and employ standard statistics such as Durbin-Watson (Sargan & Bhargava, 1983) or Student's t (Dickey and Fuller, 1979, 1981), but involve non-standard distributions for which the confidence limits are still being investigated (Engle & Granger, 1987, pp. 265-70).

The idea that economic time series such as commodity prices may follow a random walk seems, in many respects, to be counter-intuitive since the vast majority of economic theory is predicated on the assumption that there are long-run relationships between certain sets of economic variables (Granger, 1986, p. 213). In the short run, prices for a given commodity at different locations may drift apart, but, in the longer run, arbitrage will ensure that exploitable differences are removed and prices are brought back in line. Furthermore, it seems unlikely that the prices of two different commodities such as gold and corn can wander entirely randomly without reference to the value of each to the economy (Samuelson, 1976). In the long run it is the forces of supply and demand that will determine the relative price of gold and corn and not the throw of a dice.

But a new approach can also satisfy two such apparently contradictory criteria: in the short run the efficient markets hypothesis requires prices to fluctuate randomly, while, in the longer run, economic theory implies that there are forces which keep some pairs of prices in line with each other. In statistical terms this implies that there is a stable relationship between series which are I(1). Usually this would not be true since linear combinations of I(1) series in an ordinary least squares regression would typically yield a residual term that was also I(1). But Clive Granger has shown (Granger, 1986, pp. 215-8) that under certain special circumstances it is possible to have a relationship which yields a residual that is I(0). For example two price series with a strong but identical seasonal component might combine to produce a relationship which has no seasonal pattern. This condition is known as "co-integration" and has useful properties.

In particular, it is possible to specify a model which allows the long-run components of variables to obey equilibrium constraints while the short-run components have a flexible dynamic specification (Engle and Granger, 1987, p. 252). Such models are known as "error-correcting" models and may be estimated using an ordinary least squares regression to give consistent and unbiased parameter estimates. In fact, it can be shown that other commonly used techniques such as regressions based on first differences or the use of techniques like Cochrane-Orcutt which correct for serial correlation will produce inconsistent estimates and should therefore be avoided (Engle and Granger, 1987, p. 264). Such relationships could well provide an accurate characterization of the arbitrage process which links prices in different markets.

In addition, co-integration between two I(1) series implies that it must be possible to forecast one variable from the other (Granger, 1986, p. 218). This is known as "Granger" causality and has important implications for the study of price efficiency in financial and commodity markets. According to Granger (1986, p. 218), if two markets are "jointly efficient" they cannot be co-integrated since one price could be used to forecast the other which would contradict the efficient markets hypothesis. Thus gold and silver prices should not move together in the long run (Granger & Escribano, 1986). At the same time prices, for similar trading instruments in closely related markets, for example short- and long-term interest rates, appear to be co-integrated (Granger and Engle, 1987, pp. 273-4) - a result which also supports the efficient market hypothesis since the two form a linear relationship linked by a risk premium.

Whether prices are co-integrated or not is therefore a key issue in the study of financial and commodity markets since it provides a potentially interesting insight into the nature of the long-run relationship (if any) between markets and offers a simple but powerful technique for quantifying any relationship that might exist. This, as will be demonstrated later, has particular relevance to forward and futures markets since it addresses the key issue of hedging efficiency which is so important to many participants. And, where co-integration exists, there are also interesting questions about the relative efficiency of co-integrated markets since jointly efficient markets cannot be co-integrated. In these circumstances only one market can be the true centre of price discovery.

3.2 Unit Roots and Co-Integration

Recent developments in econometrics (Hendry, 1986) provide an alternative approach to the efficient markets hypothesis. As we have seen above (Section 3.1), if prices follow a random walk as suggested by Fama's theory, then the price series should have a "unit root". But testing for unit roots is not straightforward. There is no universally recommended method since the power of each test depends on the characteristics of the data generating process under investigation (Dolado & Jenkinson, 1987 pp. 13-14). Current best practice indicates that the chance of a faulty diagnosis (or Type II error) can be reduced if a variety of tests are used, some of which must be applied in sequence.

The simplest test to apply, which was proposed by Sargan and Bhargava (1983), makes use of the Durbin-Watson statistic from an ordinary least squares (OLS) regression of the time series on a constant, i.e.

$$y_t = c + u_t.$$

In a conventional OLS regression the Durbin-Watson statistic is used to test for the presence of serial autocorrelation in the residuals, i.e.

$$u_t = au_{t-1} + e_t.$$

The statistic is intended to test the hypothesis of zero autocorrelation against the alternative of positive first-order autocorrelation. Values close to 2 are usually taken to indicate that there is zero autocorrelation, i.e. $a = 0$. If the test statistic is less than 2 it indicates the presence of positive autocorrelation, i.e. $a > 0$. However, since the Durbin-Watson statistic approaches zero as the root of the error process approaches unity, the procedure can be reformulated to test whether the residual term has a unit root. In this case the null hypothesis is that the Durbin-Watson statistic is zero rather than approximately equal to two.

Critical values for the alternative hypothesis are provided by Sargan and Bhargava (1983) and it can be shown to be "the uniformly most powerful invariant test against the alternative of a stationary first order autoregressive error process" (Dolado & Jenkinson, 1987, p. 14). It has the advantage that it is not affected by the presence of a trend, but it is not very good at discrimating between a residual with a unit root and one with a root close to unity. Experiments by Granger and Engle (1987, p. 268) which compared seven different methods of testing for unit roots find that it has the best performance overall, but warn that power diminishes rapidly as the root approaches unity.

Applying the Sargan-Bhargava test to our daily series of gas oil prices over the IPE2 period (more than 900 observations) does not reject the hypothesis that forward, futures and spot prices have a unit root. The test was applied to both price levels and first differences and the results are summarized in Table 3.1. In the case of the price levels regressions the Durbin-Watson statistics from an OLS regression against a constant ranged between 0.0085 for the forward Russian market and 0.0056 for the spot barge market. These values are all very close to zero and well below the 5 per cent critical value of 0.386 calculated by Sargan and Bhargava for a sample of 100 observations.

In other words there are no grounds for rejecting the null hypothesis of a unit root. On the basis of this test gas oil prices appear to be I(1) as predicted by Fama. This result was confirmed by applying the same test to a series of first differences of gas oil prices which should be I(0) if the price levels are I(1). In this case the Durbin-Watson statistics ranged between 1.7981 for the forward market and 1.8466 for the spot non-EEC cargoes market, all of which are well above the critical value and therefore reject the null hypothesis of a unit root for the series of first differences.

An alternative, more elaborate, procedure is based on the work of Dickey and Fuller. Like the Sargan and Bhargava test it requires an OLS regression and employs non-standard distributions to obtain the appropriate critical values for the test statistic. But the procedure is more complicated since the Dickey-Fuller test involves taking the first difference of the series which is being investigated. Thus a Dickey-Fuller test for unit roots in price levels would be conducted using price changes. The reason for this is quite simple. As we have seen above (Section 3.1), the only difference between an I(0) stationary autoregressive series,

$$x_t = ax_{t-1} + e_t$$

where, $|a| < 1$ and e_t is white noise, and an I(1) random walk,

$$x_t = x_{t-1} + e_t$$

is that the coefficient on x_{t-1} is unity. Therefore if we estimate a regression based on first differences, i.e.

$$x_t - x_{t-1} = (1-a)x_{t-1} + e_t$$

the parameter (1-a) should be zero in the case of a series with a unit root. The null hypothesis of a unit root would therefore be rejected if the regression showed that the parameter on the lagged value of the price level (1-a), was significantly different from zero.

It has been shown (see for example Dolado and Jenkinson, 1987, p. 8) that the t-ratio provides an appropriate test of the significance of this parameter, and investigations by Dickey and Fuller (1979 and 1981) have provided suitable critical values for the t-statistic derived from the non-standard distribution implied by the regression. Typically critical values for the t-statistic in the Dickey-Fuller test are much larger (>3) than for a conventional OLS regression, but they can be the same under certain conditions involving either a constant or a trend in the data generating process (Dolado and Jenkinson, 1987, p. 10).

Unfortunately the test is very sensitive to the presence of a constant and a trend and it is therefore recommended (Dolado and Jenkinson, 1987, p. 13) that the Dickey-Fuller test is performed following a testing strategy that starts with an unrestricted model containing both a constant and a trend as well as the lagged value of the first difference, then moves to a regression containing just a constant and the first lag if the trend is not significant, and then to a regression with just the first lag if the constant is not significant.

In order to carry out this sequence of tests it is also important to establish which critical values should be used for significance tests. This is done using a simple regression of the first difference on a constant, and on a constant and a trend. If either of these turn out to be significant, which implies that the data generating process involves a combination of a deterministic trend and a stochastic trend, then the critical values for the t-statistic in the Dickey-Fuller test revert to their standard values (Dolado and Jenkinson, 1987, p. 11).

Applying this sequence of Dickey-Fuller tests to our daily series of gas oil prices for the post IPE2 period also does not reject the hypothesis that the forward, futures and spot prices for gas oil in North West Europe have a unit root. Once again the test was applied to both price changes as well as price levels in order to confirm the results of the tests on price levels and the results are summarized in Tables 3.2 and 3.3. In the case of the price levels it was necessary to follow the full test strategy proposed by Dolado and Jenkinson since neither the trend nor the constant were found to be significant and in many cases the value of the t-statistic fell into the difficult range between their lower conventional value (1.96 at the 5 per cent level) and the higher values computed by Dickey and Fuller (>3).

But, as was suggested by the earlier Sargan-Bhargava test on price changes (Table 3.1), there is no evidence for a significant constant or trend and so the higher Dickey-Fuller values should be used. On this basis there is no reason to reject the hypothesis of a unit root for gas oil prices since the t-statistics in all the regressions are well below three indicating that the test parameter is not significantly different from zero.

Since there was no evidence for a trend or a constant in the levels series only the simple Dickey-Fuller test was used to confirm that gas oil price changes are I(0). The results of this test are summarized in Table 3.3, which shows that the t-statistics on the lagged second difference of prices range between 26.37 for spot non-EEC gas oil and and 27.53 for the futures market. As all these values are well in excess of the 1 per cent level of 4.07 for the Dickey-Fuller test it seems safe to say that the test rejects the hypothesis of a unit root for gas oil price changes as would be expected given a unit root for price levels.

But the Dickey-Fuller test, like any OLS regression, is sensitive to the presence of autocorrelation in the error term and this will also affect the derivation of unconventional statistics (Dolado and Jenkinson, 1987, p. 11). In these circumstances Dickey and Fuller (1981) suggest that, in the case of a test for unit roots for price levels, the regression is expanded to include both a lagged price level term and a greater number of lagged values for the price diifference term in order to capture the serial correlation, i.e.

$$Dx_t = bx_{t-1} + g_n Dx_{t-n} + e_t$$

This is known as the Augmented Dickey-Fuller (ADF) test and is analagous to the error-correction model (ECM) approach to serial correlation advocated by Granger and Engle (1987). As with the ECM the regression is first estimated in its most general form with a large number of lag terms which are then progressively reduced leaving only those which are significant.

In the ADF test the null hypothesis of a unit root holds if the parameter on the lagged price level term is not significantly different from zero. As with the Dickey-Fuller test this may be tested using non-standard critical values for the t-statistic computed by Dickey and Fuller. These are slightly lower than those used in the simple Dickey-Fuller test, 3.17 at the 5 per cent level for a sample of 100 observations for example (Granger and Engle, 1987, p. 269), but still higher than their conventional value.

Inspection of the Durbin h-statistic (used because the regression involves a lagged dependent variable) for the simple Dickey-Fuller regressions reported in Table 3.2 indicates the presence of serial correlation in the error term since the h-statistics are greater than 1.64 suggesting that the test should be repeated using the Augmented Dickey-Fuller procedure.

Applying the ADF test to our daily price series for gas oil in North West Europe also supports the results of the earlier tests as it does not provide any reason to reject the hypothesis of a unit root for price levels. Once again the tests were applied to price changes as well as price levels in order to confirm the results of the price level tests. The results of the unrestricted regressions (15 lags) for price levels are not shown here, but the final results from the restricted regressions are given in Table 3.4.

In the case of price levels (see Table 3.7), the values of the t-statistic for the parameter on the lagged price range from 0.94 to 1.33. These are all well below the critical value of 3.17 indicated by Dickey and Fuller and indicate that the null hypothesis of a unit root for price levels cannot be rejected. There is also some evidence that the first and fifth lag of price changes may be the cause of serial correlation in the residuals. But in the case of price changes the hypothesis of a unit root is firmly rejected by the ADF test as expected. The values of the t-statistic from the unrestricted regressions are all in excess of 7, well above the critical value of 3.77 at the 1 per cent level, indicating that the price changes are I(0).[6]

Given that spot, forward and futures price series for gas oil in North West Europe all appear to have unit roots (ie the same order of integration, I(0)) it is now important to establish whether they are also co-integrated. As was explained above (Section 3.1), co-integration is not a necessary property of economic time series, but it is an extremely useful property since it will greatly simplify the task of investigating the relationship between prices in the European gas oil market.

Testing for co-integration involves the same procedures that were used to test for unit roots. But this time they are used to investigate the time-series properties of the residual term from a "co-integrating" regression of any pair of price series. It will be recalled that this should be I(0) if the prices are co-integrated. Since the purpose of all these procedures is to test the null hypothesis of a unit root, rejecting the null of unit root for the residual term therefore implies co-integration.

The results of "co-integrating" regressions for all pairs of spot, forward and futures prices over the IPE2 period are shown in Table 3.5. Inspection of the Durbin-Watson statistic, i.e. the Sargan-Bhargava test, reveals that the residual terms from the co-integrating regressions between forward and futures prices (FONE on MONE, and MONE on FONE) do not have a unit root since the statistic exceeds the critical value of 0.511 at the 1 per cent level. Forward and futures prices therefore appear to be co-integrating over the IPE2 period on the basis of the Sargan-Bhargava test.

The same is true of the Durbin-Watson statistics from the co-integrating regressions between non-EEC gas oil cargoes and f.o.b. barges and non-EEC cargoes and EEC cargoes, which also appear to be co-integrating of the IPE2 period on the basis of this test. But it is not true for the other pairs of prices. Regressions between EEC cargoes

[6] The same sequence of tests was also applied to spot prices in the pre-IPE2 period (1983-1984) with similar results. Spot prices were consistently found to be I(1) and price changes I(0). The introduction of a futures contract did not therefore fundamentally change the character of price behaviour in the European gas oil market.

and f.o.b. barges, and forward or futures prices and any of the spot price series reject the hypothesis of a unit root for the residual term since the statistic is below even the critical value of 0.322 at the 10 per cent level. These prices, it seems, may not be co-integrated over the IPE2 period.

It is, however, important to use more than one test for unit roots since each has its limitations. Granger and Engle (1987) argue that, although the Sargan-Bhargava test is the most powerful, its short-comings in distinguishing roots close to unity prevents it from becoming a universal test. And their simulations indicate that the Augmented Dickey-Fuller test is the best to use. However, there is still some disagreement between the results.

The results of ADF tests on the residuals from all pairs of co-integrating regressions reject the hypothesis of a unit root for all but two pairs of price series: non-EEC cargoes and f.o.b. barges, and IPE futures and EEC cargoes. As can be seen from Table 3.6, which summarizes the two sets of results, this is consistent with the DW statistic in the case of forward and futures, futures and EEC cargoes, and non-EEC cargoes and EEC cargoes, but differs for the rest. It therefore confirms that forward and futures prices, and non-EEC cargoes and EEC cargoes are co-integrated over the period, but that futures and EEC cargoes are not.

Why do the results conflict for the other pairs of prices? And which result is the more plausible? Splitting the IPE2 period into a series of annual sub-samples provides a possible explanation for the divergent results from the two unit-root tests. As can be seen from the results of co-integrating regressions for all pairs of prices for each year in the sample (Table 3.7) there is more consistency on an annual basis. In the case of forward and futures prices the DW statistic universally rejects the hypothesis of a unit root for the residuals (i.e implies co-integration); this agrees with the results of tests over the entire period. But in the case of the forward and futures markets and their underlying spot market equivalents, non-EEC cargoes and f.o.b. barges, the DW statistic in 1986 is too low to reject the hypothesis of a unit root. ADF tests, however, on the residual terms from each of these regressions reject the hypothesis of a unit root in every year confirming the results of the whole period tests above. It seems likely therefore that, since the price collapse in 1986 was responsible for some highly erratic spot price behaviour, this has affected the reliability of the tests.

If we accept that 1986 was an aberrant year in terms of price behaviour, what conclusions can we draw from the results described above? First, it seems clear that forward and futures prices are co-integrated over the entire period whichever test or sub-division of the data is employed. Furthermore the events of 1986 do not seem to have affected the strong relationship between the two series.

Secondly, it seems reasonable to conclude that forward, futures, non-EEC cargoes and f.o.b. barges are also co-integrated since all these pairs of regression pass the ADF test both for the entire sample and all the annual sub-samples and only fail the Sargan-Bhargava test for 1986. Some care should be taken, however, in interpreting the results of regressions which involve 1986 data since it is clear that the spot market, either in reality or in terms of reported prices, behaved erratically when compared with forward and futures prices.

Thirdly, it appears that, while non-EEC cargo and f.o.b. barge prices are co-integrated on an annual basis whichever test is used, this does not hold for the entire period. There is a discrepancy between the Sargan-Bhargava result, which implies co-integration, and the ADF test which implies a unit root. Possibly there has been some structural change in the relationship between these two series which is masked by the annual tests, but is apparent over the entire period. Once again some care will be required when interpreting the results of analysis involving these prices.

Finally, there is some evidence that EEC cargo prices are not completely co-integrated with the rest of the market. The tests show that while the relationship between EEC and non-EEC cargoes is co-integrated both over the entire period and all annual sub-periods, the same cannot be said of the relationship between EEC cargoes and the other price series. Co-integration is rejected for 1988 in all cases, whichever test is used. It is also rejected for earlier years for some pairs and some tests but the pattern is not consistent. It appears, therefore, that the EEC cargo market started to diverge from the rest of the gas oil market in 1988 for some reason. Whether this has anything to do with the development of the forward "French flexi market" remains to be seen.

3.3 Distribution of Returns

The statistical properties of returns also have important theoretical and practical implications for anyone interested in the behaviour of prices in forward and futures markets. In particular, many of the commonly used analytical tools assume that returns conform to a normal (or Gaussian) distribution and deviations from normality are likely to undermine the validity of their results. Furthermore, the increasing popularity of options as a trading instrument has focused attention on the nature of the returns generating process since options pricing, especially in the longer term, depends critically on a reliable estimate of price volatility.

Price volatility is not a precisely defined concept, but the most frequently used measure is the variance of the distribution of returns. In the case of a normal distribution, variance, or the square of the standard deviation of returns, provides a complete description of the spread of values about the mean. This does not apply if the distribution is not normal and other parameters are required to describe the properties of the distribution.

The scale of daily price variation can be clearly seen from Figure 3.1 which shows daily returns for spot f.o.b. barge prices over the period from January 1983 to December 1988. Two features are immediately apparent. First, there are a number of extremely large daily price movements throughout the entire period. And, secondly, there is a burst of greater price volatility during 1986 and the beginning of 1987. Once again this general pattern is common to all the price series under investigation, although the magnitude and timing of large price movements is not identical as can be seen from Figures 3.2 and 3.3, which shows daily returns for first month forward Russian and first month IPE gas oil from April 1985 to December 1988.

The presence of very large daily price movements in the sample of returns poses a problem since they can arise from data errors. In fact, some of the early studies of the behaviour of price returns in financial markets (see Fama, 1965, p. 42 for a selection of these) discarded extreme changes on these grounds. More recent studies (see Fama, 1965, Taylor, 1986), however, have found that very large price movements are a characteristic feature of returns in financial and commodity markets and should therefore be retained in any analysis. Nevertheless the largest returns were checked for errors and those that remain appear to be genuine.

If there are too many large price movements in the sample, the distribution of returns cannot strictly qualify as normal. For any distribution the proportion of extreme observations may be quantified using a measure known as "kurtosis".[7] The size of the kurtosis parameter is fixed for a normal distribution as this can be completely specified in terms of the standard deviation (or second moment about the mean) and the critical value is 3.

As can be seen from Table 3.8, which summarizes the key statistical properties of the distribution of returns for spot market prices for gas oil in North West Europe over the period from January 1983 to December 1988, all markets display excess kurtosis. But, although the value of the kurtosis parameter is very high for the sample as a whole, excess kurtosis is not found to be a persistent feature of the market once the series is split into annual sub-samples. 1986 generates the largest values for the parameter in each case, but otherwise the pattern is different. C.i.f. non-EEC gas oil cargoes display excess kurtosis in 1988, c.i.f. EEC cargoes in every year, and f.o.b. barges in 1984 and 1988.

Similarly, as can be seen from Table 3.9 which summarizes the same statistics for first forward month Russian gas oil prices and first month IPE gas oil futures, these markets also display excess kurtosis. For the sample as a whole the kurtosis parameter is 17.1 for Russian gas oil and 18.5 for IPE gas oil. However, breaking the sample down into annual sub-samples also does not reveal an entirely consistent picture. Excess kurtosis occurs three out of the four years for the IPE but only two out of four for Russian gas oil. In both cases the greatest excess kurtosis occurs in 1986, as might be deduced from Figures 3.2 and 3.3, but the IPE also displays excess kurtosis in 1985 and 1988 while the Russian market displays it in 1987.

Fama (1965, p. 55ff) suggests two possible explanations - apart from data errors - for the presence of excess kurtosis in the distribution of returns. One suggestion is that the distribution of returns is a mixture of normal distributions with substantially different variances. The most likely reason for this is that new information likely to affect prices arises continuously, while markets trade during working hours on working days. Week-ends and other holidays thus create a backlog of new information that must be taken into account when the market opens. Price changes on Mondays and days after public holidays might therefore be greater than on other days of the week. An alternative explanation is that the distribution is non-stationary. This does not rule out the possibility that the distribution of returns at any moment is normal, but it implies that the key

[7] defined as the fourth moment about the mean

parameters that characterize the distribution, the mean and the variance, are gradually changing over time. This might occur, for example, if there is a trend in the data or if the market perception of risk were to change.

The possibility of a Monday effect was investigated by regressing daily returns on a constant and a dummy variable representing Friday. Lags of the dummy variable were also included to represent the other days of the week. Tests were conducted on the entire sample of returns for each price series, for sub-samples of the spot price series corresponding to the forward and futures price data, and for annual sub-samples within that period. But the results show that in no case were Monday's returns significantly different from zero which rules out this hypothesis as an explanation for excess kurtosis. This result is consistent with other studies of commodity markets (Taylor, p. 41-42) which also failed to find a Monday effect. The Monday effect only appears to operate in the case of stock market returns which have been found to be negative.

During the latter part of the sample period, however, significant effects were found for other days of the week. Returns were found to be negative and significantly different from zero in 1987 and 1988 for c.i.f. EEC cargoes on Wednesdays and for f.o.b. barges and first month IPE gasoil on Thursdays. The presence of such effects on days other than Monday are more difficult to explain since there is clearly no backlog of information waiting to be processed by the market but similar effects have been found for currency markets (see Taylor p. 41-42) where they are thought to be the result of the clearing system. No such effects have been found for agricultural commodity markets. In the case of the spot market for gas oil in North West Europe the effect may be due to the publication of the influential US API stock figures on Tuesday nights.[8] As they are a new phenomenon it is possible that they are due to the growing importance of forward and futures markets in the oil industry. These effects also help to explain excess kurtosis in returns since they correspond to some of the years in which excess kurtosis is observed. But they do not provide a complete explanation since excess kurtosis is also a feature of other markets and other years, notably 1986 which was the year of the price collapse.

The alternative hypothesis of a trend was also tested using the basic descriptive statistics compiled for each series. But, as can be seen from Tables 3.8 and 3.9, there is no evidence for this in any of the gas oil price series employed in this study. Despite the very large change in prices that occurred during the sample period, a Student's t-test does not indicate that mean returns are significantly different from zero in any case. Furthermore, this result also holds when the sample is split into annual sub-periods and even a turbulent year such as 1986 fails to generate a negative mean that is significantly different from zero. Trends in the data cannot therefore be the explanation for the excess kurtosis observed for the distribution of returns.

Changes in the perception of risk do provide a credible explanation for the presence of excess kurtosis in 1986 since the general collapse in the level of oil prices during the first half of the year seriously affected confidence in the operation of forward markets and

[8] I am also grateful to Walter Greaves for this suggestion.

greatly increased uncertainty about the future course of oil prices. It is not, however, an hypothesis that can easily be tested since there is no independent measure of risk that can be used. In options pricing risk and price volatility are synonymous and are quantified in terms of the standard deviation of returns. But the presence of excess kurtosis can render this approach invalid. As can be seen from the basic descriptive statistics summarized above the greatest spread in returns is to be found in 1986, the year of the price collapse and the year with the greatest kurtosis. Nevertheless it is possible that the perception of risk varied widely even within 1986 and that smaller samples of returns are necessary to achieve normal distributions of returns.

Options pricing models, for example the Black and Scholes formula, measure volatility as the annualized variance of returns (see Chassard, pp. 37-39). The variance may be computed over any period of time as long as sufficient (at least 10) observations are used to obtain representative results. The underlying assumption in all these models is however that price volatility remains constant (this is because they assume a normal distribution for returns). But, as can be seen from Figures 3.4 and 3.5, which show the annualized standard deviation of returns for spot non-EEC gas oil returns over a moving 60-day period from March 1983 to December 1988, price volatility in the gas oil market has been far from constant. From March 1983 to December 1985 the annualized standard deviation moved in a range between 10 and 20 per cent. In 1986, however, volatility increased sharply, rising rapidly to a peak of about 85 per cent in June and July, before falling back in sudden steps to around 35 per cent at year end. Price volatility remained between 35 and 45 per cent for the first six months of 1987 and then dropped again to move in the range from 20 to 30 per cent until the summer of 1988. In the latter part of 1988 volatility jumped sharply again to the 40 to 50 per cent level.

Taken in isolation these shifts in the behaviour of returns could be used to argue that the growth of the forward market for Russian gasoil and the introduction of the new IPE gas oil futures contract have led to much greater volatility in spot gas oil prices. Such a conclusion would, however, be erroneous for two reasons. First, it ignores the fact that similar shifts in volatility have been observed across a wide spectrum of oil markets during this period (Chassard, 1987, pp. 34-44), and Nymex "Energy in the News", 3Q 1988, p. 20, p. 30) And, secondly, it does not take into account the important changes that took place in the structure of supply in the oil market during 1986. In particular the introduction of netback pricing by Saudi Arabia in late 1985 temporarily disrupted the normal equilibrating mechanisms that moderate supply in response to shifts in demand and greatly increased the general level of uncertainty as prices began a downward spiral.

3.4 Independence of Returns

The most commonly tested version of the efficient markets hypothesis is that daily returns should be serially independent. If they are not then the past behaviour of prices can be used to predict the future because prices will continue to change, at least in the short run, in the absence of new information. Such serial dependency may arise for many reasons, for example new information likely to affect prices may not be available to all participants at the same time leading some to act before others. An extreme example of this would be insider trading on a stock market, but the same effect may be created by other, more innocent inefficiencies.

In reality, it is unlikely that markets can achieve perfect serial independence since all institutions suffer from some form of inefficiency. But it should be possible for markets to achieve a level of efficiency which reduces serial dependency to a level that cannot be exploited by participants. This will happen when the profits made from following trading rules based on patterns of serial dependence are less than the costs of applying the rules. Any practical definition of market efficiency must therefore allow for a limited degree of serial dependence in returns.

Testing for serial independence in commodity market price returns is not, however, entirely straightforward. Many tests yield biased results in the presence of non-normal and possibly non-stationary distributions of returns. In these circumstances it is appropriate to use a non-parametric test such as the Wallis and Roberts runs test. It has the advantage of being a simple test to apply which avoids the potential problems introduced by changes in the variance of returns, but it suffers from the disadvantage of being a low power test because the data must be transformed before the test is carried out (see Taylor pp. 140-141).

The Wallis and Roberts runs test (Wallis & Roberts, 1956) is based simply on the direction of price changes. In order to carry out the test, daily returns are converted to a series of observations describing the direction of change: up or down, plus or minus, or heads or tails. Any sequence of changes in the same direction constitutes a "run" and a run ends when the direction is reversed. If prices do not change these observations may either be excluded or an alternative version of the runs test may be used which allows for the possibility of no change in prices. These observations were excluded in the analysis which follows.

The test compares the number of runs observed with the number that would be expected if the series of price changes were randomly generated and the null hypothesis is that the pattern of runs is random. Too few runs, i.e. price changes persist in the same direction for longer than expected, indicate trends in the data; while too many runs, i.e. prices change more often than expected, indicate price reversals. The test statistic, "z", assumes that the distribution of the number of runs can be approximated by a normal distribution and is calculated[9] from the actual number of runs, the mean number of runs, and the standard deviation of the number of runs. Large positive or negative values of z mean that the sequence is not random and the critical value at the 5 per cent level is 1.96. Positive values greater than 1.96 imply too many runs and negative values less than -1.96 imply too few runs.

Application of the runs test to the spot, forward and futures markets for gas oil in NW Europe finds that the sequence of price changes is non-random in every case (see Table 3.10). The test statistic is universally negative and less than the critical value of -1.96 implying that there is a tendency for prices to move in the same direction for longer than expected. And, as can be seen from the table, this result applies to spot market prices before the introduction of the second IPE futures contract as well as after. Test statistics

[9] Z = (R-m)/sigma, where: R is the actual number of runs in the sample, m is the mean number of runs, and sigma is the standard deviation of the number of runs (see Chassard & Halliwell, 1986, p. 33).

are closer to the critical value in the post IPE2 period for c.i.f. EEC cargoes and f.o.b. barges, but further away in the case of c.i.f. non-EEC cargoes. But the overall range of values is not very great, lying between -6.49 for c.i.f. EEC cargoes in the post-IPE2 period to -2.33 for the first month IPE gas oil contract.

More conventional tests for serial autocorrelation also indicate the presence of serial dependency in the gas oil markets in North West Europe. Regressions of daily returns for forward and futures prices on lagged values for the same series yield significant[10] positive first order lag coefficients. The first order lag coefficients are very similar, 0.092 for the first forward period Russian returns, and 0.089 for the first month IPE gas oil returns. In addition, longer lags were also found to be significant: lag 5 for the Russian market and lags 5 and 8 for the IPE contract. Interestingly these longer lags were also quite large but negative: -0.12 for lag 5 Russian and IPE returns and -0.08 for lag 8 IPE returns. Such a combination of positive and negative lag coefficients suggests that the forward and futures markets are not only slow to react to and absorb new information but also have a tendency to overreact at first.

Applying the same tests to spot market returns over the IPE2 period yields a range of results. Spot non-EEC cargoes returns display an almost identical pattern to the first forward month Russian returns. This is not surprising since this is the underlying commodity that is being traded on the forward paper market. As can be seen the first and fifth order lag coefficients are significant but the first is positive and the fifth is negative. This indicates that spot non-EEC gas oil prices are also slow to respond to new information and suffer from the same tendency to overreact at first. Spot EEC cargoes, however, show a different pattern. In this case it is the first and second order coefficients that are significant and both are positive. This indicates that EEC gas oil prices are potentially slower than non-EEC prices to absorb new information, but that they do not tend to overreact to the same extent. Finally, spot barges do not display significant dependence at all during the IPE2 period.

This result conflicts with the evidence from the runs test described above and may be spurious since a further sub-division of the IPE2 period provides evidence for serial dependence in 1987-1988, but not for 1985-86. It will be recalled that the level of price volatility rose dramatically towards the end of 1985 and during the first half of 1986 and the resultant distribution of returns may therefore yield unreliable results. A similar sub-division of the IPE2 period for spot non-EEC and EEC cargoes produces more consistent results. In the case of non-EEC cargoes serial dependence is apparent in both periods although the significant lags shift from a positive first order lag in the period 1985-86 to a positive third and negative fifth order lag in the period 1987-88. In the case of EEC cargoes the pattern changes from positive first and second order lags in the earlier period to positive first and third, and negative sixth order lags in the later period. Serial dependence remains a feature of all the spot market prices during the IPE2 period, although the patterns appear to have changed over time.

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[10] A non-normal distribution of returns will bias the parameters and affect significance level, but tests by Taylor, 1986, pp. 161-71, show that very similar results are obtained from rescaled returns, although their correct interpretation is unclear.

Evidence for serial dependence in spot gas oil prices, is not, of course, confined to the period during which the forward and futures markets for gas oil are active. The same tests reveal serial dependency in returns for all three spot markets in the pre-IPE2 period from January 1983 to March 1985. Significant large positive first order lags were found in each case together with significant large negative lags at higher orders. The sixth lag was significant in the case of non-EEC and EEC gas oil cargoes, while the tenth lag was significant for barges. New institutions such as forward and futures markets have not therefore done anything to slow down the rate at which these spot markets absorb and reflect new information. Whether they have improved matters remains to be seen.

3.5 Leads and Lags

One of the main arguments in favour of futures markets is that they improve price efficiency. Such improvements arise because participants can obtain information at a lower cost than from a more fragmented and less transparent market such as the spot market. Price efficiency is, however, a relative concept since all existing markets display some degree of inefficiency. In particular, inefficiency appears to be a common feature of the spot, forward and futures markets for gas oil in North West Europe since all three types of market are slow to absorb and reflect the impact of new information on prices. Nevertheless it is possible that one type of market structure is more efficient than the others and may therefore serve as a centre of price discovery for the market as a whole.

The question of price leadership can be investigated using a set of statistical techniques known as "causality tests". Such tests do not, of course, attempt to establish "causality" in any deep philosophical sense, but rely instead on a more pragmatic statistical definition of causality proposed by Granger in a paper published in the journal *Econometrica* in 1969. In order to reduce the issue of causality to a testable form Granger suggests that it is defined purely in terms of predictability. Thus if past values of a time series Y_t contain information that not only helps but also improves the prediction of another series X_t then Y is said to "cause" X (Granger, 1969, p. 430).

Such a definition can only be applied to time series data since the concept of "causality" employed requires prior information from Y to be used to predict X. As a result the length of time between data samples may be critical in determining whether or not one series "Granger causes" another. If, for example, prices are only sampled weekly or monthly when the lags in price adjustment are a matter of a day or two at the most, then it would not be possible to demonstrate that Y "causes" X. In fact it would probably appear that the two series were simultaneously determined. Alternatively a spurious causal relationship may be inferred if the samples are not taken simultaneously. Comparisons between closing prices in markets operating in different time zones around the world may give the impression that one market reacts more quickly than the other. Sampling times and intervals must therefore be selected carefully if the true structure of leads and lags in the process of price formation is to be established.

In the case of the gas oil market in North West Europe daily data were used as this appears to be the shortest interval for which truly comparable price information is available. Although the IPE futures exchange quotes prices almost continuously throughout the day there is no equivalent source of spot or forward price assessments.

Argus assessments are made at and for the close of business on each working day (1700hrs) and are disseminated by telex and fax to subscribers. The equivalent price for the futures market is the closing price published by the exchange at the end of each trading day. This has the additional advantage of being the price at which all trades are "marked to market" for the purpose of margin calls by the exchange. Thus if closing prices on the IPE futures market respond more rapidly than prices in the spot or forward markets it will be because of genuine institutional differences and not the result of sampling errors.

There are two archetypal methods of testing for Granger causality between pairs of price series, X_t and Y_t. In his original paper Granger proposed a simple procedure that involved regressing current values of one series, X_t, on lagged values of both series and testing to see if lagged values of the second series, Y_t, play any role in explaining current values of the first series. Regressions are performed using standard ordinary least squares (OLS) techniques, and an F-Test is used to test whether excluding lagged values of Y_t has any effect on the explanatory power of the regression (Granger, 1969). This is known as the "Granger Test" after its author. An alternative method was proposed by Sims in a later paper published in 1972 and involved regressing the second series, Y_t, on past and future values of the first series, X_t and testing to see if future values of X_t are determined in any way by past values of Y_t. This is known as the "Sims Test".

Both tests are sensitive to the presence of serial correlation in the residual term from the regression as the estimation is performed using OLS techniques. Unfortunately this problem cannot be ignored since serial correlation is endemic to regressions between time series involving daily prices for closely related markets. Serial correlation is, in fact, a necessary product of the dynamic arbitrage that occurs between the spot , forward and futures markets for a commodity such as gas oil given that prices are not determined instantaneously and simultaneously in all markets. And this, of course, is precisely what we are trying to investigate. For this reason it is not really appropriate to use conventional techniques to remove or counteract the effects of serial correlation in residuals. Serial correlation must therefore be accommodated by any estimation technique that is used to test for Granger causality between gas oil prices.

Simulations by Geweke, Meese, and Dent (1983) of the performance of a number of alternative estimation techniques indicate that the problem of serial correlation in residuals is best tackled using one of two procedures. Both are simple variations of the original Granger and Sims tests which incorporate sufficient numbers of the lagged dependent variable to ensure that the residual error term is serially uncorrelated. In its original form the Granger test did not specify how many lagged values of the dependent variable should be included so serial correlation might still occur. And the Sims test did not include lagged values for the dependent variable at all since the objective of the test was simply to determine whether current and past values of the independent variable play any role in predicting future values of the dependent variable. Interestingly, these Wald variants performed substantially better than all the other procedures tested by Geweke, Meese, and Dent, especially those which required the data to be corrected for serial correlation before estimation as recommended for the original Sims test (GMD, 1983, p. 185). In addition, the Wald variants are simple to compute and may be estimated using standard OLS techniques.

Applying the two Wald variants of the Granger and Sims tests to the spot, forward and futures markets for gas oil in North West Europe produces some interesting results. All regressions were performed using price changes rather than price levels, and five lags of the dependent variable were used for each test as this appears to be sufficient to remove serial correlation in the residual term from the OLS regressions. Tests with longer lags did not yield significantly different results.

In the case of the forward and futures markets both the Granger test and the Sims test indicate that past price changes in the IPE gas oil futures market play a significant role in explaining current price changes in the forward Russian market and not vice versa (see Table 3.11). The F-statistics for both the Granger test (regressing past changes in the IPE price on current changes in the Russian price) and the Sims test (regressing future changes in the Russian price on current changes in the IPE price) are significant at the 1 per cent level, while those for the reverse regressions are not. In other words the futures market appears to lead the forward market and is therefore more "efficient" in the sense that it absorbs and reflects new information more rapidly than the forward market.

If, however, the IPE2 period is split into annual sub-samples it becomes clear that the relative efficiency of the two markets has changed over time. The strongest results are obtained for the earlier part of the period and the clear lead of the futures market over the forward market gradually disappears over time. As can be seen from Table 3.11, the F-statistic for past changes in the IPE from the Granger test is significant at the 1 per cent level in 1985 and 1986, at the 5 per cent level in 1987 and not significant at all in 1988. And the F-statistic for the future price changes in the forward Russian price from the Sims test is significant at the 1 per cent level in 1985, not significant in 1986, significant at the 5 per cent level in 1987 and not significant in 1988.

There are two possible explanations for this relative improvement in the efficiency of the forward market. First, it seems likely that the forward market has benefited from the development of the futures market. After all there is no reason why participants in the forward market should not benefit from the more rapid and less costly dissemination of information via the futures market. Futures prices are available equally to forward and futures markets participants. Initially, however, many forward market participants were reluctant to use the futures market because they experienced difficulties trading a sufficiently large number of contracts to match the quantities being traded on the forward market (see above, Chapter 2). Price changes on the futures market were therefore probably discounted by forward market traders, even when they reflected new information and not just temporary shifts in an illiquid market.

During this early period forward prices therefore followed futures prices because forward market prices took longer to reflect new information as the market was generally less transparent. Once techniques such as the "screen-cross" evolved, that allowed forward market participants to use the futures market without the risk of adverse price movements, both the level of liquidity and the relevance of the futures market to forward market traders increased. As a result the time lag between changes in futures market prices and forward market prices became shorter. Finally the links between the two markets became formalized as the forward Russian market started to trade at a differential to the IPE. Once this happened the IPE gas oil futures contract became the formal centre of price discovery, but at the same time the forward market also became an extension of the futures market trading an alternative specification of the commodity under different terms.

The second explanation is that these changes reflect improvements in the standard of reporting by Argus or greater willingness by participants in the forward market to give up-to-date price information to Argus reporters now that the futures market exists as an alternative source of prices. Probably both explanations are relevant. During the last year Argus have started to make explicit assessments of price differential between the forward Russian market and the IPE futures market closing price. This is a formal recognition of the gradual changes that had been taking place in the way in which the market traded Russian gas oil. Thus it seems that both the underlying market, and the version that is available for analysis based on Argus price assessments have converged on the IPE contract as a reliable guide to price trends in the gas oil market in North West Europe.

In the case of the three major spot markets for gas oil there is also a hierarchy of efficiency. As can be seen from Table 3.11, the F-statistics from Granger and Sims tests carried out for the full period from January 1983 to December 1988 indicate that there is two-way causality between changes in barge prices and changes in both both non-EEC and EEC cargo prices. Changes in non-EEC cargo prices, however, appear to lead changes in EEC cargo prices suggesting that the non-EEC market is the centre of price discovery for the c.i.f. (imported) cargo market as a whole. This is not an unreasonable result given the magnitude of gas oil imports from the Soviet Union in relation to other, EEC qualified, sources (see Chapter 2 above).

If the same tests are applied to annual sub-samples the results become more difficult to interpret. In 1983 the F-statistics indicate that there is two-way causality between all three pairs of markets. This would be expected if each market was equally inefficient. The strongest (i.e. significant at the 1 per cent level) two-way relationship is observed for non-EEC cargoes and barges, but two-way relationships are observed for at least the 5 per cent significance level in the other two pairs of markets. But in 1984 and 1985 the F-statistics indicate one-way causality between the three pairs of markets. Price changes in the non-EEC cargo market lead price changes in both the EEC cargo market and the barge market although the tests were only significant at the 5 per cent level in the case of the EEC cargo market. One possible explanation for this improvement in the efficiency of the non-EEC cargo market could be the introduction of the forward Russian market during this period (see Chapter 2 above).

Although the forward market is probably less transparent than the futures market it is nevertheless an improvement on the spot market since standardized paper contracts improve both liquidity and transparency. The introduction of the forward market, which is based on non-EEC cargoes, might therefore have improved the pricing efficiency of the spot market for non-EEC cargoes relative to the other markets which had no effective forward or futures dimension. At the same time the relationship between the EEC cargo market and the barge market becomes confusing. In 1984 the F-statistics indicate a weak (5 per cent) lead from the EEC cargo market, but in 1985 the causality is reversed to a strong (1 per cent) lead from the barge market. There is no good explanation for this unless it reflects shifts in the fundamental balance of imports and exports in the North West European market between the two years.

During the next three years there is no consistent pattern of causality between the three spot markets. In the case of the non-EEC cargo and barge markets the strongest lead comes from non-EEC cargo market. The F-statistics show at least one-way causality in this direction at the 1 per cent level for all three years. In 1986 there is also weak causality from barges to non-EEC cargoes and strong causality in the same direction from the Granger test in 1987. Similar results were obtained for the non-EEC cargo and EEC cargo market in 1986 and 1987, but not for 1988. In 1986 and 1987 there is strong one-way causality from non-EEC to EEC cargoes and weak causality in the reverse direction from the Granger test in 1987. In 1988, however, there is weak causality from the EEC market to the non-EEC market from the Sims test and weak two-way causality from the Granger test.

Such a reversal in causality is surprising given the over-riding tendency of the EEC cargo market to follow both the non-EEC cargo and barge markets in the preceding years. Furthermore it might be possible to dismiss it as a weak result except for the fact that a similar reversal indicating strong causality from the EEC cargo market is also observed for the EEC cargo and barge markets. However, the evidence from the co-integration tests described above, indicate that these results must be treated with caution.

The EEC cargo market does not appear to be completely co-integrated with the rest of the market - especially in 1988 - which may undermine the validity of the causality tests (Engle and Granger, 1987). Nevertheless, co-integration was established for the non-EEC cargo market and the EEC cargo market in 1988, and it is possible, therefore, that the evolution of the forward dimension to the EEC cargo market in the form of the French Flexi market has helped to improve the efficiency of the EEC cargo market at a time when gas oil imports from EEC qualified sources are playing a more important role in the North West European gas oil market.

Finally, there does not appear to be a constant relationship between the three spot markets and either the forward or futures markets as might be expected if the latter were significantly more efficient than the underlying spot markets (see Table 3.11). Both the Granger and Sims tests indicate strong two-way causality between the spot non-EEC cargo market and the forward and futures markets for the IPE2 period as a whole, but tests on annual sub-samples reveal that two-way causality was strongest at the start of the period and was no longer detectable at the end. This could also be interpreted as an improvement in the relative efficiency of the three markets as a result of the move to IPE related pricing.

The two tests yielded conflicting results in the case of the spot barge market. For the period as a whole the Granger test indicates strong one-way causality from both the forward and futures market to the barge market, and weak causality from the barge market to the forward market. The Sims test, however, indicates strong two-way causality for both forward and futures. In the case of the futures market these results can be explained by the fact that tests on annual sub-samples show that two-way causality was strongest at the start of the period but gives way to strong one-way causality from futures to spot barges in 1987 and 1988. But, in the case of the forward market, they are at odds with the results of tests on annual sub-samples which only show strong one-way causality from the forward market to the barge market.

Lastly, it is interesting to find that the relationship between the spot EEC cargo market and the forward and futures market also appears to show a reversal in causality during 1988. As we found with the spot barge market above, the results of the two tests for the period as a whole indicate strong causality from forward and futures to spot, but weak causality from spot to futures for the Sims test, and weak causality from spot to forward for both tests. Applying the same tests to annual sub-samples for the futures market also shows that two-way causality is strongest at the start of the period before giving way to one-way causality from futures to forward.

In 1988, however, as we found for the spot markets, the causality is reversed and the tests show one-way causality from spot to futures. A similar reversal was also observed for the forward market, although only at a weak level. However, as we saw in Section 3.2 above, it was not possible to demonstrate co-integration between the EEC cargo market and the forward and futures market in 1988. Consequently these results should be treated with caution, and it is difficult to derive any conclusions from them, other than to suggest once again that the introduction of the forward market for EEC qualified gas oil may have changed the structure of the European gas oil market.

4 HEDGE EFFICIENCY

Price insurance is frequently portrayed in the promotional literature circulated by exchanges as one of the main advantages of using futures markets. The basic idea is very simple and depends on the assumption that futures prices move in parallel to the underlying spot market. Thus companies which buy or sell futures contracts against the sale or purchase of the physical commodity are able to "insure" themselves against the consequences of a rise or fall in spot prices since losses on the spot position will be entirely offset by gains on the futures position.

Unfortunately, as we have seen above, futures prices do not always move in parallel to the underlying spot market. The price differential, or "basis", between spot and futures contracts can be extremely volatile in the short run, and, furthermore, the price of every contract must ultimately converge with the spot market by the time it expires if the delivery mechanisms are working properly. Futures markets therefore cannot be guaranteed to provide complete insurance against adverse price movements. Nevertheless, some degree of protection is possible as long as the relative price variation does not exceed the absolute price variation during the period in which the two positions are held. In the jargon of futures markets this type of insurance is called "hedging" and the degree of protection offered by a given futures contract can be measured in terms of its "hedge efficiency".

4.1 Measuring Hedge Efficiency

The traditional view of hedging as an equal and opposite transaction on the futures market provides a simple definition of hedge efficiency that compares the risk arising from the relative variation of spot and futures prices as a result of hedging, with the risk arising from the absolute variation of spot prices as a result of not hedging. Thus,

HEDGE EFFICIENCY = 1 - VAR(RELATIVE)/VAR(ABSOLUTE).

If spot and futures prices move in parallel, then there will be no relative price variation and the hedge will be perfect, i.e. a hedge efficiency of unity. Perfect hedges are, however, unlikely since spot and futures prices rarely move in parallel, but as long as the relative price variation is less than the absolute price variation then hedging will reduce risk and hedge efficiency will have a positive value between zero and unity. If, however, the relative price variation is greater than the absolute price variation then "hedging" would actually increase risk and hedge efficiency would be negative.

This simple definition of hedge efficiency was elaborated by Ederington (1979) to encompass the portfolio approach to hedging. Portfolio theory treats hedging as just another investment decision in which the hedger tries to maximize the returns from a combination of spot and futures market positions subject to the constraint that risks should be minimized. This more flexible view of hedging allows the hedger to buy and sell different quantities on the spot and futures markets (as long as the circumstances are favourable). In fact there is no necessity to take an opposite position on the futures market, as happens with a traditional hedge. But, as Ederington points out, the spot market position is treated as fixed and the decision therefore becomes what proportion of the spot position should be hedged. This is known as the "hedge ratio".

According to Ederington (see Appendix 2 for the derivation of this relationship) the hedging efficiency of any spot-futures combination can be approximated by the sample coefficient of determination (or the squared correlation coefficient) from the regression and the risk-minimizing value of b, b^*, will be given by the estimated value of the regression coefficient for the independent variable, the change in the futures price. Unfortunately, this relatively simple technique is fraught with difficulties, and Ederington's original paper has generated a large and often contentious literature concerned with practical and theoretical attempts to overcome the problems. Most of the literature is concerned with the (empirical) question of whether the regression coefficient, or "hedge ratio" is significantly different from unity. But, as will be seen below, the debate is overshadowed by the (practical) question of how to estimate the ratio.

Ederington himself investigated the relative hedging efficiency of two new financial markets (GNMAs and T-Bills) and two well-established agricultural commodity markets (corn and wheat) based on regressions involving two- and four-week price changes. He found that cash and futures prices do not change by equal amounts, and that in three out of the four markets the empirical results indicated an optimal hedge ratio of less than unity (the exception was corn). He also found that, in the case of the financial markets, hedging efficiency improved for the longer-term hedges. Although his paper actually contained two mistakes which were identified and corrected by Franckle (1980), these conclusions remained robust and set the pattern for much of the subsequent work.

Cichetti, Dale & Vignola (1981) and Maness (1981) also investigated the hedging efficiency of the T-Bills market and obtained similar results to Ederington and Franckle, i.e. an optimal hedge ratio of less than unity and better hedging efficiency with longer hedges. Interestingly, Cichetti, Dale, & Vignola suggest that "the longer hedge allows the market time to smooth out short-run price fluctuations". And Maness compared the results of a naïve (one for one) hedging strategy with Ederington's optimal hedge ratio on an *ex post* and *ex ante* basis. *Ex post*, he found that optimal hedges are better than naïve hedges and that the hedge ratio was less than unity. But, *ex ante* (which is the problem facing the hedger in the real world), naïve hedges were better than optimal hedges, from which he concluded that the distribution of future returns in the T-Bill market cannot be established from past data.

Hill & Schneeweis (1981 & 1982) and Hill, Liro & Schneeweis (1983) applied the Ederington approach to foreign currency futures (1981, 1982) and GNMA futures (1983) and also found that optimal hedge ratios were typically less than unity and that longer hedges improved hedging efficiency. In addition they compared the hedging efficiency of contracts with different times left to delivery and of futures and forward contracts for foreign exchange. In the case of contracts of different maturities, they found that for GNMAs (1983) efficiency improved as the contract approached delivery, but for foreign currency futures (1982) the nearby contract is not always best. And, in the case of forward and futures contracts, they found that there was no difference between the two for the DM and British pound, but that the forward yen market was more efficient than the yen futures contract.

Hill & Schneeweis (1981) also started an important debate over the best method of measuring hedging efficiency and estimating hedge ratios, which has yet to be resolved. In their 1981 paper in the *Journal of Futures Markets* they criticize an earlier paper by Dale (1981) which used price levels rather than price changes as the basis for regressions between spot and futures prices. Unlike the other papers discussed above Dale found that regressions using price levels yielded hedge ratios that were not significantly different from unity. In particular, they argue that Dale's use of price levels is not only inconsistent with the theoretical formulation of the hedging problem, but also leads to inefficient estimates of hedge ratios; over-states the effectiveness of hedging; and biases the standard error of the hedge ratios so that standard statistical tests are invalid. And they demonstrate this by presenting the results of regressions using price levels and price changes for the same set of foreign currency futures data which show that price level regressions yield low Durbin-Watson statistics (i.e. have autocorrelated residuals).

The issue of levels or changes was taken up by Brown (1985) in a controversial paper in the *American Journal of Agricultural Economics*. Like Hill and Schneeweis, Brown argues that price levels cause econometric problems and lead to inefficient estimates of hedge ratios. Unfortunately Brown believed that both the portfolio model and Ederington's 1979 paper were based on price levels rather than price changes. He therefore proposed an alternative specification of the portfolio model based on returns (i.e. percentage changes in prices). This was then applied to three agricultural commodity futures markets (wheat, corn and soybeans) using weekly (Friday closing) prices and the results compared with regressions using price levels. And, since his results showed that hedge ratios for levels are significantly different from unity, while those from returns are not, he argued that the paper does not support the portfolio model of hedging.

Brown's paper was strongly criticized by Kahl (1986) who drew his attention to the fact that Ederington used price changes in the derivation of the portfolio model of hedging and his empirical work. She also pointed out that Brown's results were at odds with those of both Hill & Schneeweis (1981) and Dale (1981). Finally, she argued that there was no reason why a hedge ratio of unity should not support the portfolio model of hedging since it simply represents a special case of the more general theory. Brown (1986) subsequently admitted his error over Ederington's formulation of the portfolio model of hedging, but maintained that the magnitude of the hedge ratio is a useful guide to the relevance of portfolio theory to the hedging problem. In other words, if ratios are typically unity, there is little point in worrying about it since a naïve hedge will be perfectly adequate. Brown also replicated Ederington's regressions for wheat using returns and levels as well as changes for two- and four-week hedges but finds that only one of the price change ratios was significantly different from unity. In general he finds that the ratio is larger for regressions involving levels than those involving changes or returns.

Witt, Schroeder & Hayenga (1987) continued the debate over "the best procedure to estimate minimum risk hedge ratios" in the *Journal of Futures Markets*. At the theoretical level they concede that there are important conceptual differences between the use of levels, changes and returns. For example, price changes may be more appropriate for a storage hedge and price levels for an anticipatory hedge (see Anderson and Danthine, 1981). But they point out that these "measures of hedging effectiveness reduce to the coefficient of determination in all regression models". There are also important practical differences when it comes to comparing and interpreting the results since "the dependent variable is not the same in any of these models". Hedge ratios estimated from returns are particularly difficult to interpret since they represent a ratio based on value rather than physical units.

In practical terms, however, they favour price level regressions because these do not make any assumptions about the length of the hedge: "For a given contract, the same hedge ratio can be used regardless of the length of time to maturity. With differencing models, each time the hedging period is changed, a new hedge ratio must be estimated. Therefore, although only one hedge ratio need be estimated for each contract using price-level regressions, several may need to be estimated using differencing models." After comparing the results from each method for three-month cross-hedges between nearby futures contracts for three agricultural commodities (barley, sorghum and corn) they concluded that:

> the price-level model is theoretically sound and preferred to the change models except when:
>
> (1) the cash-futures price relationship is non-linear in the levels,
> (2) the price-level equation exhibits strong k-th order auto-correlation, and
> (3) first order (and similar low order) autocorrelation occurs in the price level model.

The question of whether to use price levels or price changes in estimating hedge ratios therefore appears to be a practical question which depends on the time-series characteristics of the data involved. In the case of price levels regressions, as we have seen above (Chapter 3), autocorrelation in the residuals is probably inevitable for regressions between pairs of commodity prices. For this reason, most researchers reject the use of price levels on the grounds that the parameter estimates will be biased, and use price changes instead.

However, as we have also seen above, this is not necessarily the case and it is possible to obtain reliable parameter estimates in the presence of autocorrelated residuals as long as the two series can be shown to be co-integrated. In fact, if they are co-integrated, then the use of techniques which correct for serial correlation (e.g. Cochrane-Orcutt) or regressions based on price changes can lead to biased parameter estimates. Thus it may be the higher (not significantly different from unity) hedge ratios obtained from price levels regressions that are correct rather than the lower (significantly different from unity) ratios obtained from regressions based on price changes.

This hypothesis has important implications for hedging in general since it implies that using estimated hedge ratios of less than unity could be an expensive mistake. Interestingly, it is consistent with the results of research which compare the performance of *ex post* and *ex ante* hedges. Both Maness (1981) and, more recently, Lasser (1987) find that, *ex ante*, naïve (one-for-one) hedges out-perform hedges based on optimal ratios estimated using price changes. It is also consistent with the common result obtained from studies using price changes that the size of hedge ratio increases with the length of the hedge. If it takes time for financial and commodity markets to adjust to the impact of new information, then a longer sampling interval will tend to reflect the true equilibrium relationship between the two series.

4.2 Hedging Efficiency and Optimal Hedge Ratios

Forward and futures markets shift the focus of attention from absolute prices to relative prices. Thus both hedgers and speculators are concerned with the behaviour of the price differential, or basis, between the hedging instrument and the underlying spot commodity. As we have seen above, hedge efficiency depends on the stability of the basis which may fluctuate for a variety of reasons. Furthermore, in the case of the gas oil market in North West Europe, participants are concerned with the basis relationships between an array of alternative trading instruments and a set of clearly differentiated spot markets for the same commodity. The question of hedging efficiency must therefore be extended to cover cross-hedging between the forward and futures markets and the underlying spot markets for c.i.f. non-EEC cargoes and f.o.b. barges.

As was shown in Section 2.3, the mean differential between the c.i.f. non-EEC market and the first forward month Russian paper market was not statistically different from zero and the standard deviation was relatively large ($5.96/tonne) indicating a wide range of values about the mean. Similar results are obtained for the IPE gas oil contract, but the mean and the standard deviation of the basis between the f.o.b. barges market and the first futures month are much larger. The average spot premium was $3.12/tonne and the standard deviation was $8.58/tonne.

Breaking the period down into annual sub-samples (see Table 4.1) reveals a number of interesting features of basis behaviour for the forward and futures markets. First, it becomes clear that the extreme volatility of the basis is confined to 1986, the year of the price collapse, and that the standard deviation of the basis in each market is much smaller in 1985 and 1987-88. Thirdly, it seems that the greater volatility of the barge-futures basis is not a quirk due to the extremes of 1986, but is observed consistently for all the years in the sample.

The story becomes even more interesting if the same simple statistics are calculated for cross-hedges between the forward and barge markets, and the futures and non-EEC cargo markets (see Table 4.1). Similar broad patterns are observed for the IPE2 period as a whole and the individual years, but this time the relative volatility of the basis is reversed for every year except 1985. Thus the standard deviation of the mean basis is larger for the forward market than the futures market in 1986, 1987 and 1988.

The differences, however, are much smaller than we observed for the direct hedges in the two markets and it can be seen that the cross-hedge non-EEC cargo-futures basis is actually less volatile than the direct barge-futures basis in those years. In addition, it appears that the cross-hedge barge-forward basis is also less volatile than the direct barge-futures basis in every year. Thus, it appears that the forward market may be a more effective hedging instrument for both the underlying non-EEC cargo market and the barge market, which is the underlying commodity for the IPE gas oil futures contract.

These provisional conclusions are supported by more formal estimates of hedge efficiency calculated along the lines indicated by Ederington (1979, above) for the case of a naïve hedge (which assumes equal and opposite positions on the spot and forward or futures markets). In this case hedge efficiency is defined as,

$$e = 1 - Var(H)/Var(U),$$

where, Var(H) is the variance of the hedged position, which is equivalent in this case to the variance of the changes in the basis, and Var(U) is the variance of the unhedged position, which is equivalent to the variance of the changes in spot prices.

As can be seen from Table 4.1, which compares the variance of the changes in the basis for direct hedges in the forward and futures markets, with the variance of the changes in prices for the underlying spot commodities, the hedging efficiency of the forward Russian market is consistently better than that of the IPE futures market. This is true for the period as a whole and for every year in the sample. However, it also appears that the gap in hedging efficiency between the two markets has narrowed over the period and that, while hedging efficiency has improved in both markets, it has improved more in the futures market than in the forward market.

In 1985, the first year of the new IPE contract, the hedging efficiency of the futures market was only 36 per cent, much poorer than that of the Russian forward market which achieved 62 per cent. Not surprisingly, hedging efficiency fell sharply in 1986 as the basis became very unstable during the price collapse. For the Russian forward market hedging efficiency fell to only 16 per cent as the variance of the changes in the basis rose close to the variance of the changes in the underlying non-EEC cargo market. And, for the IPE futures market, hedging efficiency became negative since the variance of the changes in the basis actually exceeded the variance of the changes in the underlying barge market. In 1987, however, the peak year for the forward market, hedging efficiency in the futures market rose sharply to 63 per cent, compared with 79 per cent in the Russian forward market. And, in 1988, hedging efficiency in the futures market continued to improve reaching 69 per cent, while hedging efficiency in the forward market fell back to 74 per cent.

In the real world, hedging is much more difficult than is implied by the simple examples quoted in text-books. Hedgers must accept that spot and futures prices rarely move in parallel and act accordingly. In some cases this will affect the timing of a hedge. Companies are often unwilling to hedge when the price differential between the spot and futures (or forward) contract is widening. They prefer to wait until the basis starts to narrow and will hold the hedge as long as it moves in their favour. Others need to hedge routinely, but choose to hedge only a proportion of their physical position on the grounds that the futures contract is unlikely to provide a perfect hedge. Both strategies are based on observations of the past behaviour of spot and futures prices.

The theoretical justification for hedging only a proportion of the physical position is provided by Ederington (1979), who shows that both hedging efficiency and the optimal (risk-minimizing) hedge ratio can be directly estimated from an ordinary least squares regression of the change in futures prices on the change in spot prices,

$$DSP_t = a + bDFP_t + e_t,$$

where, DSP_t, and DFP_t are the change in spot and futures prices respectively. In this case "b", the parameter on the dependent variable, is the optimal hedge ratio (see Section 4.1 above). And the correlation coefficient (R^2) is a measure of hedging efficiency. Most published studies of hedging efficiency use this method, and it is also widely used by companies who wish to estimate optimal hedge ratios.

As we have seen above, Witt, Schroeder & Hayenga (1987) show that the same result can be obtained from a regression in price levels rather than price changes, and recommend that this approach is used, except where the cash-futures price relationship is non-linear in the levels, or there is evidence of strong auto-correlation. And, recent work on co-integrating regressions by Granger and Engle (1987) shows that levels regressions will yield unbiased parameter estimates if the two price series are co-integrated even if there is autocorrelation in the residual term. Indeed, they go further, and argue that it is the price change regressions that will yield biased parameter estimates unless they include an error-correction term.

Previous studies (see Section 4.1 above) have debated the merits of the two approaches without reference to the recent advances in the study of co-integrated variables, and have generally concluded that it is the price level regressions that generate biased parameter estimates - largely because of the endemic problem of autocorrelation in the residuals from regressions between pairs of commodity price series. But it has also been convenient to be able to dismiss the results of levels regressions because these typically yield hedge ratios that are either close to unity or not significantly different from unity. In these circumstances there is little point in trying to estimate optimal hedge ratios, since a naïve hedge will do the job. And, in the real world, this is what matters.

What are the implications for hedgers in the forward and futures markets for gas oil in North West Europe? Which method should be used to measure hedging efficiency and estimate optimal hedge ratios? Does it affect the relative hedging efficiency of the two markets? And, is there a significant difference in the optimal hedge ratio implied by the two estimation techniques?

As far as the method is concerned, there is strong evidence in favour of co-integration between the four pairs of price series (see Section 3.2 above). Consequently, levels regressions will provide unbiased estimates of optimal hedge ratios for both direct and cross hedges. These parameters can be obtained from the co-integrating levels regressions for futures and forward prices on spot prices shown in Table 3.5 above. And the results are summarized for convenience in Table 4.2. The regressions were then repeated using daily price changes rather than price levels in order to compare the two techniques, and the results are shown in Table 4.3.

As far as hedging efficiency is concerned, the two methods yield very similar results. That is to say that the relative hedging efficiency of the forward and futures market for direct and cross hedges is the same, since it is not possible to compare the results directly because the dependent variable is different for each technique. Both the levels regression and the price change regressions indicate that the Russian forward market is a consistently better hedging instrument for non-EEC cargoes than the IPE futures market is for f.o.b. barges. This result holds over the entire IPE2 period, for the post-1986 period, and for every year in the sample. And it can be demonstrated by comparing either the correlation coefficient (R^2) or the standard error of the estimate (SEE) from the direct hedge regressions for the forward and futures markets reported in Table 4.2. Furthermore, it is consistent with the results obtained for a naïve hedge which were reported above.[11]

There is also broad agreement from the results obtained for cross-hedges between the forward and barge markets and the futures and non-EEC cargo markets. Over the entire IPE2 period the forward market appears to be a better hedging instrument than the futures market, but this result does not hold once the sample is sub-divided. Regressions covering the post-1986 period indicate that the relative cross-hedging efficiency of the two markets was reversed and the futures market performed better than the forward market.

But, on an annual basis, the two methods yield different results for 1986 and 1987 (see Tables 4.2 & 4.3) The levels regressions indicate that the forward market was a better cross-hedging instrument in 1987 and the futures market in 1986, while the price change regressions indicate the reverse. Neither result is entirely consistent with the results obtained for naïve hedges, which show that the futures market was a better cross-hedging instrument from 1986 onwards. However, all three methods indicate that there has been a shift in the relative cross-hedging efficiency of the two markets between 1985 and 1988, although they disagree on the timing of the switchover.

As far as the optimal hedge ratio is concerned, however, the two methods yield widely different results. In the case of the co-integrating levels regressions the optimal hedge ratios for both direct and cross-hedges based on regression over the entire IPE2 period are slightly above unity, while those from the price change regressions are substantially less than unity (see Table 4.3). Both sets of ratios are significantly different from unity, but the levels regressions imply a hedge ratio of between 1.03 and 1.04 units of forward or futures contracts to each unit of the physical commodity, while the price change regressions imply a ratio of between 0.58 and 0.80. In other words, companies which take hedging decisions based on optimal hedge ratios derived from price change regressions may seriously underestimate the size of the futures or forward market position required to provide a risk-minimizing hedge.

The substantial difference in the optimal hedge ratios implied by the two techniques is apparent whichever period is used to carry out the regressions. In the case of the post-1986 period (when relative prices are more stable) the hedge ratios from the levels

[11] Conflicting results were obtained for relative hedging efficiency in 1986 for the price change regressions. R^2 implies that the forward market was better than the futures market, but SEE implies the reverse. In this case R^2 alone was taken as the guide.

regressions are not significantly different from unity for both direct and cross-hedges in each market (see Table 4.2), while the ratios from the price change regressions are, and range between 0.84 and 0.87 (see Table 4.3). In the case of the annual sub-samples, the hedge ratios from the levels regressions are not significantly different from unity in 1985 and 1987, and are significantly different but close to unity in 1986 and 1988. In the case of the price change regressions, the hedge ratios are all significantly different from zero and range between 0.45 and 0.59.

As we have seen above (Section 3.2), 1986 was a particularly difficult year for the market in which forward, futures and spot prices did not always move closely together. So it is not surprising to find that the hedge ratios from even the levels regressions are significantly different from unity. And it is in 1986 that the lowest hedge ratios from the price change regressions are to be found. But, it is curious to find that the hedge ratios from the levels regressions for 1988 are also significantly different from unity. Indeed, both the direct and cross-hedge regressions imply that ratio of the forward or futures position to the spot position should be of the order of 1.1, which is much larger than is indicated for any of the other years except 1986.

Why are the two sets of results so different? In statistical terms, the problem is one of dynamics. Prices in any network of closely related markets continuously react to each other as new information becomes available. In a perfectly efficient market this interaction is instantaneous and prices adjust accordingly. In the real world, especially the imperfect real world of the physical oil market, the interaction is not instantaneous and takes place over a period of hours or even days. Consequently, regressions between daily price series for markets such as the spot, forward and futures markets for gas oil in North West Europe are likely to be affected by this continuing interaction which manifests itself in the form of serial correlation in the residuals.

As was explained above (Section 3.1) co-integrating levels regressions sucessfully capture such short-run variations in the relative level of prices and provide an accurate estimate of the true long-run relationship between the two price series. But this is not the case with price change regressions; these cannot distinguish between the short-run and long-run relationships since they force them to converge over the period chosen for the price change. Thus it is the short-run disequilibria between the spot and forward or futures prices which bias the results downwards and generate hedge ratios well below unity. In the longer run, as can be seen from the co-integrating levels regressions, the relationship between the spot, forward and futures markets for gas oil in North West Europe is much closer and a naïve hedging strategy would probably be perfectly adequate. Certainly, the reluctance of some companies to hedge when the basis is widening, appears to make statistical as well as practical sense since it indicates an awareness that longer-run relationships will inevitably bring the markets back into line.

Overall, it now seems that there is little to choose between the forward and futures market as far as hedging efficiency is concerned. Any initial disadvantage suffered by the IPE futures market has now disappeared as its level of liquidity has grown. Although the forward contract was still marginally more effective than the futures contract for direct hedges, the futures contract is almost as effective for cross-hedges of non-EEC gas oil. And there seems to be strong circumstantial evidence that this is what the majority of hedgers were really doing. This conclusion is supported by the analysis of price ratios presented in Section 2 and the hedge ratios estimated from the co-integrating levels regressions above. If the IPE were to change the delivery specification on its futures contract to reflect the true source of the hedging pressure in the market, it might finally be able to replace the forward market for Russian gas oil in all its dimensions. Until then there remains a complementary role for the Russian market as a delivery mechanism for non-EEC cargoes.

5 CONCLUSIONS

Two types of conclusion emerge from this study. First, there are conclusions that are specific to the structure of the European gas oil market. These go some way towards explaining why there are so many different trading instruments for one commodity. But, secondly, there are observations of a more general sort which could be applied to the study of any commodity market. These help to clarify some of the theoretical aspects of market performance that lie behind the practical problems faced by traders as they try to assess relative price behaviour in order to determine arbitrage opportunities and hedge ratios.

On balance, the evidence supports the hypothesis of an integrated market for gas oil in North West Europe. Although the standard tests for price efficiency reveal that there are too many large returns for a normal distribution, that there is evidence of serial correlation, and that there are too many runs for a pure random walk, it appears that forward, futures and spot price series have a unit root and that any deviations from the random walk are therefore short lived. Whether such deviations are exploitable is another issue, but it seems likely that gas oil prices will satisfy the requirements of a martingale and that excess returns and serial correlation are the result of less-than-instantaneous adjustment of gas oil prices to new information.

Furthermore, the evidence rejects the hypothesis of independent random walks. Extensive tests of the relationship between prices in the various gas oil markets both over the period and for a variety of sub-periods indicate that co-integration is the norm. Although there are some periods and tests which reject the hypothesis of co-integration, the majority do not. In addition, since "co-integration implies causality", tests of the leads and lags between pairs of gas oil markets do not reject the hypothesis of "Granger" causality in the gas oil market complex. Interestingly, it is the IPE gas oil futures contract that emerges as the centre of price discovery in most cases, a result that seems entirely credible given the much greater level of price transparency associated with a screen market. However, markets are never static, and it is also interesting to observe that the clear lead of the futures market over the forward market in the early years was replaced by simultaneous causality once the forward market started trading at a differential to the futures market.

The question of hedging efficiency is much more contentious given that the academic literature is not agreed about the best method of estimation. Several approaches were used in this study and the results compared. Using co-integrating levels regressions generates much higher levels of *ex post* hedge efficiency than most other methods and also suggests that the optimum *ex ante* hedging strategy may be the "naïve" hedge. The lower levels of hedge efficiency implied by other methods are probably the result of biased estimates from regressions which fail to take account of the slow speed at which prices adjust in these markets rather than evidence for independent price behaviour. Similarly the fact that hedge ratios of less than unity are often recommended is probably the result of the less-than-instantaneous arbitrage process between the spot, forward and futures markets.

Nevertheless, whatever technique is used, it appears that the Russian forward market is a better hedging instrument for non-EEC cargoes (the underlying commodity in the forward market) than the IPE gas oil futures contract is for f.o.b. barges (the underlying commodity in the futures market). The same was also true for cross-hedges between the two markets during 1985 and 1986. However, the hedging efficiency of the futures market has improved considerably since the new contract was launched in late 1984 and the gap between the two has narrowed. And it now seems that the IPE is at least as good as the forward market for cross-hedges. In fact, there is strong circumstantial evidence from the comments of traders and the evolution of relative prices over the period that many companies use the IPE futures market in order to hedge non-EEC cargoes rather than barges.

If gas oil markets are integrated but prices are not identical, why are there so many different trading instruments? Clearly, differences in quality and origin combine to separate the non-EEC cargo market from the EEC cargo market. But these are not constant factors and the price differential between the two varies with the seasons. In addition differences in timing separate the barge market from the cargo market. Once again this is not constant and varies with the size of the backwardation or contango in the forward and futures markets. Timing also separates the spot markets from the forward and futures markets and the seasonal pattern of backwardation and contango appears to reflect the seasonal behaviour of stockholders in the ARA region.

But there are other, less obvious, factors. Spot, forward and futures markets have very different levels of price transparency. Although Argus' assessments reflect a standardized spot commodity the spot market itself is much less standardized. Finding buyers and sellers, negotiating prices and agreeing deals takes much longer in the spot market and information is not freely available to all concerned. And, although forward markets are based on standardized commodities, buyers and sellers still need to find each other and information still takes time to circulate. Futures markets, however, are much more transparent and, as long as there is sufficient liquidity in the market, enable participants to complete transactions quickly at known prices.

It seems likely that it is these differences in the level of price transparency that account for the slow rate of price adjustment between the spot, forward and futures markets. In the short run the markets may be out of line because price changes in one market have not yet been reflected in price changes in the other market. But even such short-run uncertainty creates risks for companies and impairs the cross-hedging efficiency of a single futures contract for different varieties of the spot commodity. Thus even if the IPE gas oil futures contract remains the dominant market, there will still be room for the forward contracts in the Russian and French flexi markets as long as the short-term basis risk persists.

But the question of differentiation has a more general application. As we have seen above, economic theory suggests two types of relationship between prices in differentiated markets. On the one hand, differentiated prices could be statistically independent. In this case the markets will be jointly efficient, which means that prices cannot be co-integrated and there will be no causal linkages between them. Each market therefore acts as an independent centre of price discovery since the information set driving price changes will be different in each case. And the hedging efficiency of a forward or futures contract will be poor since there is no long-run stable relationship between the trading instrument and the spot commodity.

On the other hand, differentiated prices could be statistically dependent if they belong to an integrated market. In this case the markets are not jointly efficient, prices will be co-integrated and there will be causal linkages between them. Consequently there can only be one centre of price discovery since prices change in all markets as the result of the same information set. And the hedging efficiency of a forward or futures contract will be good since there is a long-run stable relationship between the trading instrument and the spot commodity. Effective hedging therefore depends on the existence of integrated markets.

APPENDIX 1

SOURCES OF INFORMATION

Comparisons between spot, forward and futures markets can never be perfect since it is not possible to obtain a complete set of information concerning transactions on an informal telephone market that has no central exchange and where participants have no obligation to report details of their trading activity. In the case of oil, information on prices and transactions on the spot and forward markets is collected from a representative sample of participants by specialist reporting agencies before being assessed and disseminated by newsletter, telex or some other electronic means.

Generally speaking, the information published by the reporting agencies is considered to be accurate and a fair representation of price levels and market activity, but it is always possible for some participants to disguise or delay the publication of particularly sensitive data. Such delays can be to the advantage of the larger players who often have access to better information as a result of their greater presence in the market and help to explain the preference of many large companies for informal forward transactions. Smaller players, however, prefer the greater price transparency which is offered by a futures exchange which records and disseminates information concerning all transactions as they occur.

The number of reporting agencies has increased rapidly in the last few years as the volume of oil trading has grown and as new forms of information technology have become available. The best known and most widely used sources of spot prices are *Petroleum Argus* and Platt's. *Platt's Oilgram Price Report* is the longest established, it began in the United States over 60 years ago and, until recently, its daily assessments of spot product prices provided an almost universal reference point for term contracts that employ price formulae. *Petroleum Argus* was established in 1970 as a specialist European spot market report but it now also has worldwide coverage. It has always taken particular care to distinguish between the different grades of gas oil traded on the Rotterdam spot market and was the first reporting agency to provide detailed reports for the new forward markets in crude oil and products as they developed in the early 1980s.

Daily spot bid and ask price assessments for c.i.f. non-EEC gas oil, c.i.f. EEC gas oil and f.o.b. barges over a period from 1983 to 1989 were kindly supplied in a computer readable form by Petroleum Argus Ltd. Daily bid-ask assessments for the forward Russian market over a period from 1985 to 1989 were obtained from the Argus Atlantic Products telex. Daily high, low and closing prices for the first six contract months of the IPE gas oil futures contract over a period from 1985 to 1989 were kindly supplied in a computer readable form by Saladin Computer Systems Ltd.

Forward and futures market prices also pose problems for anyone interested in studying their behaviour over a long period of time since each contract has a finite life. It is therefore necessary to choose between a series composed of prices for a single contract with constantly diminishing maturity and one composed of prices for more than one contract in order to obtain a sufficiently large number of observations.

In the case of the forward market for Russian gas oil the choice is constrained by short trading horizons. Only three forward periods are actively traded and so a single contract would only provide a small number of observations. Since the second and third forward months are not really suitable because the market did not trade this far forward in its early life, the only feasible contract is the first forward month. This also has the advantage of being the most liquid contract at any moment. Long series of forward Russian gas oil prices can therefore only be obtained by joining together the prices from successive first forward months. But this must be done carefully to avoid introducing unrepresentative price movements where two months are joined together.

In the case of the IPE futures market there is a wider choice of contract months since up to eight months may be traded at any time. In theory this would also allow us either to study the behaviour of one contract month from inception to maturity as is often done in the case of agricultural commodity markets, or to create long series of prices with fewer joins. In practice, however, it seems sensible to use the same approach for the IPE market as was imposed for the Russian market in order to ensure compatibility between the two price series. This view is supported by the fact that the nearby months on the IPE also display the greatest liquidity.

In both cases it was therefore decided to construct a series drawn from prices for the first forward or futures month. Thus during January, Russian gas oil prices for 1-15 February and IPE gas oil futures for February were used in the series. The average of the bid-ask spread quoted by *Petroleum Argus* was used for Russian gas oil and the daily closing price was used for the IPE gas oil futures contract. The sample contract month changes at the start of each calendar month, so that from the first working day in February, the sample is taken from 1-15 March Russian gas oil prices and March IPE gas oil futures.

Joining contract months together in this fashion can cause problems if there is a large jump in price from one contract month to the next. In these circumstances it is suggested that any analysis based on price changes or "returns" should incorporate the price change based on the new contract month rather than the change from the old to the new contract on the day when the contracts rollover. But this is really an empirical problem and can only be resolved by statistical analysis.

The possible existence of rollover "errors" was investigated by testing to see if price changes on the first working day of each month were significantly different from zero for either of the constructed series. Neither series, however, revealed any problems. A sample of 35 daily returns for Russian gas oil over a period from May 1985 to December 1988 yielded a Student's t-statistic of 1.56 and a sample of 39 daily returns for IPE gas oil over the same period yielded a t-statistic of 1.36. Both of these are below the critical value at the 1 per cent level. It should be noted that there are fewer observations than months in the sample because non-trading days such as bank holidays sometimes fall at the start or end of a month and that there are fewer observations in the case of Russian gas oil due to missing data over the turn of some months.

None of these difficulties arise for spot price series since these have constant maturity. In the oil products market spot usually means for delivery up to a specified number of days ahead. Argus f.o.b. barges are assessed on the basis of delivery over a period 5-15 days ahead and cargoes on the basis of delivery over a period of 10-20 days ahead. Spot gas oil price series were therefore prepared by taking the average of the daily bid-ask spread quoted by *Petroleum Argus* for the three main markets, c.i.f. EEC cargoes, c.i.f. non-EEC cargoes and f.o.b. barges.

APPENDIX 2

HEDGE EFFICIENCY

The derivation of the simple definition of hedge efficiency is quite straightforward, but it is worth repeating here because it is important to understand how the traditional view of hedging can be elaborated to include the portfolio approach and, furthermore, why this can lead to practical problems in the estimation of hedge efficiency for commodity futures markets.

Following Ederington (1979), we define the return from holding an unhedged quantity, XS, of the spot commodity for any period of time as a function of the expected change in spot prices over that period,

$$E(U) = XS.E(PS2-PS1),$$

where, E(U) is the expected return on the unhedged position, and E(PS2-PS1) is the expected spot price change over the period t1 to t2.

Thus, if we measure risk as the variance of returns - which assumes a normal distribution for returns (see Chapter 3 above) - the risk from remaining unhedged can be expressed as,

$$Var(U) = XS^2.Var(PS),$$

where, Var(PS) is the variance of the expected distribution of spot price returns over the period.

Similarly, the return from holding a futures contract is a function of the expected change in futures prices over the same period,

$$E(F) = XF.E(PF2-PF1)$$

where, E(F) is the expected return on the futures position, and
E(PF2-PF1) is the expected futures price change over the period t1 to t2.

and, the equivalent measure of risk is,

$$Var(F) = XF^2.Var(FP),$$

where, Var(FP) is the variance of the expected distribution of futures price returns over the same period.

The return from hedging, which involves opposite spot and and futures positions, can therefore be obtained by taking the difference of the expected returns from each of the two contracts,

$$E(H) = XS.E(PS2-PS1) - XF.E(FP2-FP1),$$

where, E(H) is the expected return on the hedged position.

But, in the case of a traditional hedge, where the quantities are identical (i.e. XF=XS=X), this may be rearranged and reduced to,

$$E(H) = X.E\{(FP2-SP2)-(FP1-SP1)\},$$

which expresses the expected return from hedging in terms of the change in the relative prices of the spot and futures contracts over the period. Thus the risk of holding a traditional hedge can be expressed as,

$$Var(H) = X^2.Var(FP-SP),$$

where, Var(FP-SP) is the variance of the expected distribution of the changes in the spread (basis) between futures and spot prices.

Thus the effectiveness of hedging in reducing risk may be expressed as,

$$e = 1 - Var(H)/Var(U),$$

where, e is a measure of hedge efficiency. This in turn is relatively easy to compute since it only requires two simple statistics, the variance of the distribution of spot price returns and the variance of the distribution of changes in the basis.

If we remove the constraint the futures and spot market positions are of the same size, then the expected return, R, from a portfolio that includes both spot and futures contracts will be the sum of the expected returns from the two separate contracts,

$$E(R) = XS.E(PS2-PS1) + XF.E(PF2-PF1),$$

and so the risk characteristics of the portfolio can be described by the joint probability distribution of expected returns from the two markets,

$$Var(R) = XS^2.Var(PS) + XF^2.Var(PF) + 2XS.XF.Cov(PS,PF),$$

where, Var(R) is the variance of returns from the portfolio, and Var(PS), Var(PF), and Cov(PS,PF) are the variances and covariance of the distribution of expected returns for spot and futures prices.

If we now express the size of the futures market position, XF, as -b.XS, where b is the proportion of the spot market position that is hedged (i.e. the hedge ratio), the expected return from hedging becomes,

$$E(R) = XS\{E(PS2-PS1)-b.E(PF2-PF1)\},$$

which is equivalent to,

$$E(R) = XS\{(1-b)E(PS2-PS1)+b.E(PS2-PS1)-b.E(PF2-PF1)\},$$

$$= XS\{(1-b)E(PS2-PS1)-b.E((PF2-PS2)-(PF1-PS1))\},$$

where, E(PS2-PS1) is the expected change in spot prices, and E((PF2-PS2)-(PF1-PS1)) is the expected change in the spread between futures and spot prices.

Thus the expected return from hedging is a function of both the expected change in the basis and the proportion, b, of the spot position which is hedged. If the basis remains constant, as assumed in the popular example of a traditional hedge, the expected return will tend towards zero as b approaches unity. In other words there will be no profit or loss from hedging. But, if the basis changes, the expected return will also vary depending on the value of b. Thus hedgers may profit from expected changes in the basis by varying the proportion of the spot commodity which is hedged as described by Working.

The variance of returns from hedging can also be rewritten in the same fashion as,

$$Var(R) = XS^2\{Var(PS) + b.Var(PF) + 2b.Cov(PS,PF)\},$$

which implies (by differentiation) that the risk-minimizing value of b, b^*, will be,

$$b^* = Cov(PS,PF)/Var(PF).$$

If we now substitute the risk-minimizing value of b, b^*, into the equation (above) which describes the variance of expected returns from hedging, we obtain the minimum variance, R^*, of the hedged portfolio,

$$Var(R^*) = XS^2\{Var(PS) + (Cov(PS,PF))^2/(Var(PF)$$

$$- 2[(Cov(PS,PF))^2/Var(PF)]\},$$

$$= XS^2\{Var(PS) - (Cov(PS,PF)^2/Var(PF)\}.$$

which should now be used to measure the hedging efficiency of the risk-minimizing portfolio. Thus,

$$e = 1 - Var(R^*)/Var(U),$$

or, substituting for $Var(R^*)$ and Var(U),

$$e = 1 - XS^2\{Var(PS)-(Cov(PS,PF)^2/Var(PF)\}/XS^2.Var(PS),$$

which reduces to,

$$e = Cov(PS,PF)/(Var(PS).Var(PF))$$

This is equivalent to the population coefficient of determination between the changes in the spot price and the change in the futures price (Ederington, 1979, CBOT p. 90). As a result it should be possible to measure the hedging efficiency of a risk-minimizing portfolio by regressing changes in spot prices against changes in futures prices.

APPENDIX 3

TABLES

Table 2.1: Simple Statistics: Price Differentials and Ratios.

MARKETS	PERIOD	PRICE DIFFERENTIALS			PRICE RATIOS			
		Mean	Std Err	t-stat:0	Mean	Std Err	t-stat:0	t-stat:1
Spot FOB Charges vs Spot Non-EEC Cargoes	1983-88	2.122	3.536	.600	1.010	.020	51.551	.531
Spot FOB Charges vs Spot EEC Cargoes	1983-88	-1.420	3.334	-.426	.991	.020	50.027	-.429
Spot EEC Cargoes vs Spot Non-EEC Cargoes	1983-88	3.554	2.907	1.223	1.019	.017	61.481	1.164
Spot FOB Charges vs Spot Non-EEC Cargoes	1983-84	3.536	2.609	1.355	1.015	.011	95.672	1.377
Spot FOB Charges vs Spot EEC Cargoes	1983-84	-.995	2.595	-.383	.996	.011	94.046	-.374
Spot EEC Cargoes vs Spot Non-EEC Cargoes	1983-84	4.531	2.239	2.023	1.019	.009	113.690	2.087
Spot FOB Charges vs Spot Non-EEC Cargoes	1985-88	1.411	3.750	.376	1.008	.023	43.922	.366
Spot FOB Charges vs Spot EEC Cargoes	1985-88	-1.537	3.664	-.420	.989	.023	42.453	-.458
Spot EEC Cargoes vs Spot Non-EEC Cargoes	1985-88	2.966	3.114	.952	1.020	.020	51.474	.989
Forward Market vs Futures Market	1985-88	.212	1.568	.135	1.001	.010	96.583	.058
Forward Market vs Spot FOB Charges	1985-88	-2.854	8.162	-.350	.987	.046	21.432	-.292
Forward Market vs Spot Non-EEC Cargoes	1985-88	-1.445	5.960	-.242	.994	.035	28.066	-.167
Forward Market vs Spot EEC Cargoes	1985-88	-4.417	6.422	-.688	.975	.037	26.522	-.675
Futures Market vs Spot FOB Charges	1985-88	-3.119	8.575	-.364	.986	.049	20.260	-.291
Futures Market vs Spot Non-EEC Cargoes	1985-88	-1.700	6.475	-.263	.993	.039	25.511	-.169
Futures Market vs Spot EEC Cargoes	1985-88	-4.661	7.013	-.665	.975	.041	23.028	-.625

Table 2.2: Simple Regressions: Pairwise Levels Regressions, 1983-88.

PRICES P1 vs P2	PERIOD	CONSTANT	t-stats	RATIO	t-statistics		DWS
		a	nsd O	b	nsd O	nsd 1	
1. Spot Market							
Spot FOB Barges vs Spot Non-EEC Cargoes	83-88	-1.064	-3.180	1.017	604.358	9.876	.426
Spot FOB Barges vs Spot Non-EEC Cargoes	83-84	-.134	.060	1.015	101.660	1.502	.327
Spot FOB Barges vs Spot Non-EEC Cargoes	85-88	.077	.170	1.008	370.810	2.943	.458
Spot FOB Barges vs Spot Non-EEC Cargoes	87-88	-.067	.094	1.004	207.136	.756	.827
Spot EEC Cargoes vs Spot Non-EEC Cargoes	83-88	1.833	6.548	1.009	716.820	6.372	.572
Spot EEC Cargoes vs Spot Non-EEC Cargoes	83-84	-4.763	2.340	1.038	123.490	4.521	.432
Spot EEC Cargoes vs Spot Non-EEC Cargoes	85-88	3.733	9.800	.995	439.650	-2.209	.633
Spot EEC Cargoes vs Spot Non-EEC Cargoes	87-88	1.635	2.016	1.012	181.849	2.103	.638
Spot FOB Charges vs Spot EEC Cargoes	83-88	-2.637	8.087	1.006	624.146	3.867	.279
Spot FOB Charges vs Spot EEC Cargoes	83-84	8.147	3.560	.963	103.700	-3.984	.396
Spot FOB Charges vs Spot EEC Cargoes	85-88	-3.349	7.380	1.011	381.140	4.147	.246
Spot FOB Charges vs Spot EEC Cargoes	87-88	.360	.352	.978	142.417	-3.168	.371
2. Futures Market							
Spot FOB Charges vs Futures Market	85-88	-3.902	3.680	1.044	163.940	6.909	.114
Spot Non-EEC Cargoes vs Futures Market	85-88	-4.675	5.880	1.040	217.420	8.362	.233
Spot EEC Cargoes vs Futures Market	85-88	-.987	1.130	1.035	197.460	6.677	.198
3. Forward Market							
Spot FOB Charges vs Forward Market	85-88	-2.520	2.490	1.033	170.310	5.441	.121
Spot Non-EEC Cargoes vs Forward Market	85-88	-3.280	4.460	1.029	232.620	6.556	.256
Spot EEC Cargoes vs Forward Market	85-88	.364	.460	1.025	213.190	5.200	.211
4. Forward/Future							
Forward Market vs Futures Market	85-88	-1.536	8.100	1.011	887.710	9.659	1.070

Table 2.3: Simple Regressions: Pairwise Levels Regressions with 1986 and Monthly Dummies, 1983-88

PRICES P1 vs P2	PERIOD	CONSTANT a	t-stats nsd 0	86 DUM a	t-stats nsd 0	RATIO b	t-statistics nsd 0	t-statistics nsd 1	DWS
1. SPOT MARKET									
Spot FOB Barges vs Spot Non-EEC Cargoes	83-88	-2.123	-5.519	6.308	17.605	1.019	702.298	13.320	0.609
	85-88	-1.298	-2.658	5.323	17.077	1.010	470.500	4.712	0.786
Spot EEC Cargoes vs Spot Non-EEC Cargoes	83-88	3.762	10.866	-0.485	-1.505	1.006	770.033	4.218	0.702
	85-88	5.814	12.339	0.191	0.637	0.992	478.981	-3.646	0.791
Spot FOB Barges vs Spot EEC Cargoes	83-88	-5.732	-16.523	6.762	21.125	1.013	786.477	9.857	0.482
	85-88	-6.976	-16.479	5.241	19.747	1.016	552.809	8.934	0.566
2. FUTURES MARKET									
Spot FOB Barges vs Futures Market	85-88	-8.613	-9.667	15.704	28.205	1.061	264.017	15.189	0.329
Spot Non-EEC Cargoes vs Futures Market	85-88	-7.113	-9.064	10.202	20.917	1.050	295.835	13.992	0.456
Spot EEC Cargoes vs Futures Market	85-88	-1.510	-1.843	10.336	20.290	1.043	281.535	11.684	0.437
3. FORWARD MARKET									
Spot FOB Barges vs Forward Market	85-88	-7.423	-8.661	15.288	28.327	1.049	272.850	12.825	0.344
Spot Non-EEC Cargoes vs Forward Market	85-88	-5.975	-8.117	9.719	21.082	1.038	313.632	11.565	0.489
Spot EEC Cargoes vs Forward Market	85-88	-0.331	-0.434	9.957	20.840	1.032	300.691	9.245	0.456
4. FORWARD/FUTURES									
Forward Market vs Futures Market	85-88	-1.070	-4.500	0.413	2.788	1.011	942.002	10.053	1.265

Table 3.1 - Testing for Unit Roots: Sargan-Bhargava Integration Tests
- Results OLS Regressions on Price Levels & First Difference: 1985-1988
- $P_t = a + u_t$ & $\Delta P_t = a + u_t$

DEPENDENT VARIABLE	CONSTANT	(tstat)	DWS	SEE	OBS	H_o: DWS nsd 0 (Critical Value = 0.386)
Forward Market - P_t	161.04	(113.66)	0.0085	43.44	940	Accept H_o, I(1)
- ΔP_t	-0.05	(0.37)	1.7981	3.84	912	Reject H_o,I(0)
Futures Market - P_t	161.07	(115.14)	0.0079	43.05	947	Accept H_o, I(1)
- ΔP_t	- 0.06	(0.49)	1.8313	3.70	922	Reject H_o, I(0)
Spot - P_t Spot Non-EEC Cargoes	162.27	(111.01)	0.0067	44.82	940	Accept H_o, I(1)
- ΔP_t	- 0.07	(0.63)	1.8466	3.58	911	Reject H_o, I(0)
Spot - P_t Spot FOB Cargoes	163.88	(110.35)	0.0056	45.56	941	Accept H_o, I(1)
- ΔP_t	- 0.047	(0.37)	1.8099	3.11	913	Reject H_o, I(0)
Spot - P_t Spot EEC Cargoes	165.24	(113.31)	0.0053	44.71	940	Accept H_o, I(1)
- ΔP_t	- 0.063	(0.61)	1.6626	3.09	911	Reject H_o, I(0)

Table 3.2: Testing for Unit Roots: Dickey-Fuller Tests on Levels
Results of OLS Regressions on First Differences: 1985-88

(1) DPt = a + trend + bPt-1 + ut
(2) DPt = a + bPt-1 + ut
(3) DPt = bPt-1 + ut

DEPENDENT VARIABLE	OLS REG	CONSTANT (t-stat)	TREND (t-stat)	b (t-stat)	R2	SEE	DWS	Durbin's h-stat	OBS	SE(b)
FORWARD MARKET NON-EEC CARGOES	(1)	1.388 (1.65)	-0.0004 (0.64)	-0.0078 (2.04)	0.0054	3.84	1.793	na	912	0.0037963
	(2)	0.950 (1.95)	na	-0.0062 (2.13)	0.0049	3.84	1.795	na	912	0.0029167
	(3)	na	na	-0.0007 (0.91)	0.0008	3.84	1.798	5.533252	912	0.0007633
FUTURES MARKET IPE GAS OIL	(1)	1.359 (1.67)	-0.0004 (0.73)	-0.0076 (2.04)	0.0052	3.70	1.826	na	922	0.0037015
	(2)	0.874 (1.86)	na	-0.0058 (2.06)	0.0046	3.70	1.828	na	922	0.0028214
	(3)	na	na	-0.0007 (1.00)	0.0008	3.70	1.831	4.498126	922	0.0007317
SPOT MARKET NON-EEC CARGOES	(1)	1.184 (1.51)	-0.0003 (0.52)	-0.0069 (1.97)	0.0050	3.57	1.843	na	911	0.0035033
	(2)	0.874 (1.91)	na	-0.0057 (2.15)	0.0050	3.57	1.845	na	911	0.0026558
	(3)	na	na	-0.0008 (1.18)	0.0010	3.58	1.847	3.870955	911	0.0007071
SPOT MARKET FOB BARGES	(1)	0.967 (1.39)	-0.0003 (0.63)	-0.0052 (1.71)	0.0040	3.11	1.806	na	913	0.0030414
	(2)	0.600 (1.91)	na	-0.0039 (2.15)	0.0030	3.11	1.808	na	913	0.0022573
	(3)	na	na	-0.0005 (0.82)	0.0006	3.11	1.810	4.297351	913	0.0006065
SPOT MARKET EEC CARGOES	(1)	0.990 (1.46)	-0.0002 (0.42)	-0.0058 (1.93)	0.0054	3.09	1.661	na	911	0.0030026
	(2)	0.759 (1.94)	na	-0.0050 (2.17)	0.0052	3.08	1.662	na	911	0.0022967
	(3)	na	na	-0.0007 (1.16)	0.0011	3.09	1.663	7.555738	911	0.0006003

FOOTNOTE: Null Hypothesis is that the series has a unit root ie b is n.s.d zero, where critical values are given by Dickey & Fuller, 1976

Table 3.3 - Testing for Unit Roots: Dickey-Fuller Test on First Differences
- Results of OLS Regressions: 1985-1988
- $\Delta \Delta P_t = b.\Delta P_{t-1} + u_t$

DEPENDENT VARIABLE	b (t-stat)	R^2	SEE	DWS	OBS	H_o: Unit Root is b n.s.d. 0
(1) Forward Market	-0.904 (27.14)	0.455	3.80	1.9831	885	Reject H_o, I(0)
(2) Futures Market	-0.908 (27.53)	0.458	3.68	1.9945	897	Reject H_o, I(0)
(3) Spot Non-EEC Cargoes	-0.892 (26.37)	0.441	3.55	1.9885	883	Reject H_o, I(0)
(4) Spot FOB Barges	-0.896 (26.89)	0.450	3.09	1.9855	886	Reject H_o, I(0)
(5) Spot EEC Cargoes	-0.904 (27.14)	0.455	3.80	1.9831	885	Reject H_o, I(0)

Table 3.4 - Testing for Unit Roots: Augmented Dickey-Fuller Test on Levels
- Results of OLS Regressions with Restricted Lags:1985-1988
- $\Delta P_t = b.P_{t-1} + \gamma_1.\Delta P_{t-1} + \gamma_2.\Delta P_{t-2} + \gamma_5 \Delta P_{t-5} + u_t$

DEPENDENT VARIABLE	b (t-stat)	γ_1 (t-stat)	γ_2 (t-stat)	γ_5 (t-stat)	SEE	DWS	OBS
(1) Forward Market	-0.0011 (1.33)	0.0889 (2.58)	n.a.	-0.0980 (2.83)	3.83	1.9898	825
(2) Futures Market	-0.0009 (1.11)	0.0714 (2.11)	n.a.	-0.1033 (3.04)	3.70	1.9825	839
(3) Spot Non-EEC Cargoes	-0.0009 (1.19)	0.0704 (2.01)	0.0678 (1.94)	-0.0918 (2.66)	3.45	1.9834	795
(4) Spot FOB Barges	-0.0006 (0.94)	0.0573 (1.64)	0.0528 (1.54)	-0.0468 (1.34)	3.02	2.009	801
(5) Spot EEC Cargoes	-0.0008 (1.33)	0.1717 (4.89)	0.0762 (2.24)	-0.0476 (1.43)	2.90	1.981	795

Table 3.5 - Co-integrating Regressions: Forward, Futures & Spot Prices
- Results of OLS Regressions with Price Levels: 1985-1988
- $P1_t = a + b.P2_t + u_t$

DEPENDENT VARIABLE	$P2_t$	a (t-stat)	b (t-stat)	R^2	SEE	DWS	OBS
(1) Forward Market (FONE)	MONE	-1.536 (8.10)	1.011 (887.71)	0.9988	1.498	1.070	936
	NEC	5.847 (8.47)	0.955 (232.62)	0.9831	5.612	0.258	932
	BAR	7.365 (7.87)	0.938 (170.31)	0.9689	7.654	0.124	933
	EEC	2.873 (3.75)	0.956 (213.19)	0.9799	6.1141	0.214	932
(2) Futures Market (MONE)	FONE	1.708 (9.20)	0.988 (887.71)	0.9988	1.481	1.070	936
	NEC	7.522 (10.30)	0.943 (217.42)	0.9806	5.955	0.234	936
	BAR	9.020 (9.38)	0.926 (163.94)	0.9664	7.885	0.117	937
	EEC	4.689 (5.731)	0.943 (197.46)	0.9766	6.543	0.201	936
(3) Spot Non-EEC Cargoes (NEC)	FONE	-3.280 (4.46)	1.029 (232.62)	0.9831	5.827	0.256	932
	MONE	-4.675 (5.88)	1.040 (217.42)	0.9806	6.252	0.233	936
	BAR	1.022 (2.27)	0.985 (370.81)	0.9932	3.691	0.459	939
	EEC	-2.949 (7.57)	0.9999 (439.65)	0.9952	3.116	0.634	940
(4) Spot FOB Barges (BAR)	FONE	-2.520 (2.49)	1.033 (170.31)	0.9689	8.036	0.121	933
	MONE	-3.907 (3.68)	1.044 (163.94)	0.9664	8.371	0.114	937
	NEC	0.077 (0.17)	1.008 (370.81)	0.9932	3.734	0.458	939
	EEC	-3.349 (7.38)	1.011 (381.14)	0.9936	3.633	0.246	937
(5) Spot EEC Cargoes (EEC)	FONE	0.364 (0.46)	1.025 (213.19)	0.9799	6.332	0.211	932
	MONE	-0.987 (1.13)	1.035 (197.46)	0.9766	6.854	0.198	936
	NEC	3.733 (9.80)	0.995 (439.65)	0.9952	3.109	0.633	940
	BAR	4.350 (9.93)	0.983 (381.14)	0.9936	3.582	0.246	939

Table 3.6: Summary of Co-Integration Tests
Entire IPE2 Period

DEPENDENT VARIABLE	FONE	MONE	NEC	BAR	EEC
Forward Market					
- DWS		Yes	No	No	No
- ADF		Yes	Yes	Yes	Yes
Futures Market					
- DWS	Yes		No	No	No
- ADF	Yes		Yes	Yes	No
Spot Non-EEC Cargoes					
- DWS	No	No		Yes	Yes
- ADF	Yes	Yes		No	Yes
Spot FOB Barges					
- DWS	No	No	Yes		No
- ADF	Yes	Yes	No		Yes
Spot EEC Cargoes					
- DWS	No	No	Yes	No	
- ADF	Yes	No	Yes	Yes	

Table 3.7: Summary of Co-Integration Tests, Annual Sub-Samples
(1) Sargan-Bhargara (Durbin-Watson Statistic) Test

DEPENDENT VARIABLE	FONE	MONE	NEC	BAR	EEC
Forward Market (FONE)		85-88	85, 87-88 not 86	85, 87-88 not 86	85, 87 not 86, 88
Futures Market (MONE)	85-88		85, 87-88 not 86	85, 87-88 not 86	85 not 86-88
Spot Non-EEC Cargoes (NEC)	85, 87-88 not 86	85, 87-88 not 86		85-88	85-87 not 88
Spot FOB Barges (BAR)	85, 87-88 not 86	85, 87-88 not 86	85-88		85, 87 not 86, 88
Spot EEC Cargoes (EEC)	85, 87 not 86, 88	85 not 86-88	85-87 not 88	85, 87 not 86, 88	

Table 3.7 (contd.): Summary of ADF Tests for Co-Integration, Annual Sub-Samples
(2) Augmented Dickey-Fuller Test

DEPENDENT VARIABLE	FONE	MONE	NEC	BAR	EEC
Forward Market (FONE)		85, 86, 88 not 87	85, 86 87, 88	85, 86 87, 88	85, 86, 87 not 88
Futures Market (MONE)	85, 86, 88 not 87		85, 86 87, 88	85, 86 87, 88	85, 86, 87 not 88
Spot Non-EEC Cargoes (NEC)	85, 86 87, 88	85, 86 87, 88		85, 86 87, 88	85, 86 87, 88
Spot FOB Barges (BAR)	85, 87, 88 not 86	85, 87, 88 not 86	85, 86 87, 88		not 85, 86 87, 88
Spot EEC Cargoes (EEC)	85, 86, 87 not 88	85, 86, 87 not 88	85, 86 87, 88	not 85, 86 87, 88	

Table 3.8: Daily Returns: Simple Statistics for Spot Prices, 1983-88

Spot Market, cif Non-EEC Cargoes	1983	1984	1985	1986	1987	1988	1983-88
Observations	239	245	236	241	246	251	1458
Mean ($x10^4$)	-5.477	-4.535	+3.124	-12.40	+0.467	+1.314	-2.899
Standard Deviation ($x10^2$)	0.91	1.04	1.24	3.68	1.70	1.74	1.95
Skewness	-0.889	+0.507	-0.824	+0.538	+0.245	+0.382	+0.575
Kurtosis	1.67	2.16	1.98	4.79	2.2	4.54	14.41
t-statistic (mean nsd ∅)	-0.930	-0.680	+0.388	-0.523	+0.043	+0.120	-0.568

Spot EEC Cargoes	1983	1984	1985	1986	1987	1988	1983-88
Observations	239	245	236	241	246	251	1458
Mean ($x10^4$)	-6.045	-5.091	3.759	-6.981	-1.461	1.139	-2.442
Standard Deviation ($x10^2$)	0.83	1.05	1.19	3.05	1.51	1.59	1.69
Skewness	-0.675	1.22	-1.137	+1.701	+0.560	+0.999	+1.772
Kurtosis	3.49	6.54	5.68	12.14	3.46	4.92	24.72
t-statistic (mean nsd ∅)	-1.123	-0.761	0.487	-0.356	-0.152	+0.113	-0.550

Spot FOB Barges	1983	1984	1985	1986	1987	1988	1983-88
Observations	237	245	238	239	246	251	1456
Mean ($x10^4$)	-7.394	-5.465	+5.026	-3.812	-1.774	+0.983	-2.058
Standard Deviation ($x10^2$)	0.86	0.92	1.14	3.07	1.72	1.85	1.76
Skewness	-0.603	+0.085	-0.728	+2.466	-0.185	+0.216	+2.089
Kurtosis	1.69	5.48	2.59	18.49	2.98	3.27	31.20
t-statistic (mean nsd ∅)	-1.323	-0.928	+0.683	-0.192	-0.162	+0.084	-0.445

Table 3.9 Daily Returns: Simple Statistics for Forward & Futures Prices, 1985-88.

Forward Market: First Month Non-EEC Cargoes

	1985	1986	1987	1988	1985-88
Observations	177	242	244	249	912
Mean (x 10^4)	+0.317	-9.001	-1.488	+4.952	-1.373
Standard Deviation (x 10^2)	1.19	4.18	1.74	1.78	2.56
Skewness	-0.952	-0.453	+0.262	+0.142	-0.552
Kurtosis	2.46	7.46	3.34	2.35	17.07
t-statistic (mean nsd $\emptyset$)	0.035	-0.335	-0.133	+0.439	-0.162

Futures Market: First Month IPE Gas Oil Contract

	1985	1986	1987	1988	1985-88
Observations	184	247	244	247	922
Mean (x 10^4)	-0.362	-8.356	-2.772	+2.877	-2.274
Standard Deviation (x 10^2)	1.24	3.95	1.67	1.87	2.48
Skewness	-1.731	-0.920	-0.018	0.465	-1.02
Kurtosis	8.83	9.01	1.81	3.71	18.47
t-statistic (mean nsd $\emptyset$)	-0.040	-0.332	-0.260	+0.241	-0.278

Table 3.10: Wallis & Roberts Runs Test, 1983-1988

MARKET	N	n_1	n_2	P	q	m	σ	R	Z
Forward Market	822	403	419	0.490	0.510	411.3	14.33	361	-3.51
Futures Market	922	469	453	0.509	0.491	461.4	15.17	426	-2.33
Spot non-EEC Cargoes	781	397	384	0.508	0.492	390.9	13.96	329	-4.43
[pre-Futures Market 2]	448	206	242	0.460	0.540	223.1	10.57	188	-3.32
Spot FOB Barges	802	403	399	0.503	0.498	401.5	14.15	353	-3.43
[pre-Futures Market 2]	437	213	224	0.487	0.513	218.9	10.44	181	-3.62
Spot EEC Cargoes	719	357	362	0.497	0.503	360.0	13.40	273	-6.49
[pre-Futures Market 2]	412	186	226	0.451	0.549	204.6	10.14	158	-4.59

Table 3.11

CAUSALITY TESTS

Summary of results from Granger and Geweke causality tests. Sample was split into annual sub-periods and both tests were employed. Tests use price changes. → means ≤ 1pc confidence, ⤳ means 1 ≤ 5pc confidence

(1) FUTURES MARKET vs FORWARD RUSSIAN MARKET, SPOT NON-EEC CARGOES, SPOT FOB BARGES & SPOT EEC CARGOES

PERIOD	TEST	FORWARD RUSSIAN MARKET			SPOT NON-EEC CARGOES			SPOT FOB BARGES			SPOT EEC CARGOES		
		Futures Market F-stat (%)	Causality	Forward Market F-stat (%)	Futures Market F-stat (%)	Causality	Spot Non-EEC Cargoes F-stat (%)	Futures Market F-stat (%)	Causality	Spot FOB Barges F-stat (%)	Futures Market F-stat (%)	Causality	Spot EEC Cargoes F-stat (%)
1985	Granger	3.06 (1.2)	→	1.67 (14.8)	5.21 (0.0)	↔	5.14 (0.0)	7.24 (0.0)	↔	3.42 (0.6)	13.08 (0.0)	↔	3.96 (0.2)
	Geweke	3.12 (1.2)	→	1.49 (20.1)	6.13 (0.0)	↔	4.13 (0.2)	8.22 (0.0)	↔	3.96 (0.3)	16.40 (0.0)	↔	4.09 (0.2)
1986	Granger	3.95 (0.2)	→	0.75 (58.6)	2.09 (6.8)	⬿	2.42 (3.7)	10.70 (0.0)	→	0.81 (54.6)	12.28 (0.0)	→	0.94 (45.1)
	Geweke	2.08 (7.0)	? no lags	0.52 (76.0)	2.24 (5.3)	⤳	1.73 (13.0)	14.01 (0.0)	→ ⬿	2.53 (3.1)	12.63 (0.0)	→	1.37 (23.8)
1987	Granger	2.19 (5.6)	⤳	1.06 (38.4)	5.04 (0.0)	→ ⬿	2.74 (2.0)	6.35 (0.0)	→	0.97 (43.6)	5.13 (0.0)	→	2.06 (7.1)
	Geweke	2.38 (4.0)	⤳	0.61 (68.9)	2.76 (2.0)	⤳ ←	3.88 (0.2)	5.90 (0.0)	→	1.18 (31.9)	5.49 (0.0)	→ ⬿	2.63 (2.6)
1988	Granger	0.52 (76.1)	no lags	0.96 (44.4)	1.31 (26.0)	no lags	1.09 (36.6)	5.55 (0.0)	→	1.88 (10.0)	1.86 (10.4)	←	3.04 (1.1)
	Geweke	0.86 (50.9)	no lags	1.14 (34.0)	1.83 (11.0)	no lags	0.93 (46.0)	5.05 (0.0)	→	1.00 (41.9)	1.90 (9.6)	←	3.62 (0.4)
1985-88	Granger	9.26 (0.0)	→	1.20 (30.7)	4.32 (0.1)	↔	6.74 (0.0)	24.2 (0.0)	→	1.83 (10.5)	33.30 (0.0)	→	2.07 (6.7)
	Geweke	7.17 (0.0)	→	1.03 (40.1)	5.52 (0.0)	↔	5.81 (0.0)	26.8 (0.0)	↔	4.01 (0.1)	34.61 (0.0)	→ ⬿	3.06 (1.0)

CAUSALITY TESTS (contd)

(2) Forward Market

PERIOD	TEST	SPOT NON-EEC CARGOES			SPOT FOB BARGES			SPOT EEC CARGOES		
		FORWARD MARKET	CAUSALITY	SPOT NON-EEC CARGOES	FORWARD MARKET	CAUSALITY	SPOT FOB BARGES	FORWARD MARKET	CAUSALITY	SPOT EEC CARGOES
1985	Granger	3.91 (0.3)	↔	3.54 (0.6)	4.57 (0.1)	→	1.51 (19.2)	8.54 (0.0)	→	1.97 (8.9)
	Geweke	3.22 (1.2)	→	1.77 (13.2)	4.35 (0.1)	→	1.36 (24.9)	11.76 (0.0)	→ ←	2.48 (4.1)
1986	Granger	1.54 (17.9)	←	3.11 (1.0)	5.57 (0.0)	→	0.93 (46.0)	5.60 (0.0)	→	1.05 (38.8)
	Geweke	2.33 (4.4)	→	1.72 (13.2)	8.83 (0.0)	→	1.40 (22.7)	8.2 (0.0)	→	1.13 (34.4)
1987	Granger	3.16 (0.9)	→ ←	2.51 (3.1)	3.99 (0.2)	→	0.72 (60.7)	5.10 (0.0)	→	0.85 (51.7)
	Geweke	1.02 (40.7)	no lags	1.84 (10.8)	3.75 (0.3)	→	1.01 (41.1)	4.86 (0.0)	→	1.11 (35.9)
1988	Granger	1.77 (12.2)	no lags	1.36 (24.3)	5.57 (0.0)	→	1.38 (23.2)	1.86 (10.3)	←	2.55 (2.9)
	Geweke	1.92 (9.3)	no lags	1.21 (30.5)	4.20 (0.1)	→	0.22 (95.3)	1.32 (25.6)	←	2.45 (3.5)
1985-88	Granger	3.22 (0.7)	↔	8.74 (0.0)	13.04 (0.0)	→ ←	2.62 (2.3)	16.64 (0.0)	→ ←	2.65 (3.2)
	Geweke	4.82 (0.0)	↔	5.61 (0.0)	17.91 (0.0)	↔	3.14 (0.8)	20.70 (0.0)	→ ←	2.86 (1.5)

CAUSALITY TESTS (contd)

(3) SPOT PRICES: SPOT NON-EEC CARGOES vs SPOT FOB BARGES, SPOT NON-EEC CARGOES vs SPOT EEC CARGOES, SPOT FOB BARGES vs SPOT EEC CARGOES

PERIOD		SPOT NON-EEC CARGOES	CAUSALITY	SPOT FOB BARGES	SPOT NON-EEC CARGOES	CAUSALITY	SPOT EEC CARGOES	SPOT FOB BARGES	CAUSALITY	SPOT EEC CARGOES
1983	Granger	3.56 (0.4)	↔	2.35 (0.4)	3.16 (0.9)	→ ↜	2.13 (6.4)	2.74 (2.1)	⟷	2.74 (2.1)
	Geweke	3.42 (0.6)	↔	2.63 (0.3)	2.36 (4.3)	⟷	2.34 (4.5)	2.95 (1.4)	← ↝	3.50 (0.5)
1984	Granger	3.88 (0.2)	→	1.67 (14.3)	2.97 (1.3)	↝	0.80 (55.0)	1.38 (23.4)	↜	2.97 (1.3)
	Geweke	2.59 (2.8)	→	1.36 (24.2)	2.62 (2.7)	↝	0.37 (87.1)	1.50 (19.1)	↜?	2.19 (5.7)
1985	Granger	3.52 (0.5)	→	0.97 (43.5)	6.57 (0.0)	→	1.62 (15.6)	5.24 (0.0)	→	1.46 (20.5)
	Geweke	3.94 (0.2)	→	0.77 (57.2)	7.51 (0.0)	→	1.96 (8.9)	3.44 (0.6)	→	1.89 (10.0)
1986	Granger	4.47 (0.1)	→ ↜?	2.14 (6.2)	6.67 (0.0)	→	0.35 (88.1)	1.14 (34.0)	no lags	0.73 (60.0)
	Geweke	4.11 (0.2)	→ ↜	2.68 (2.3)	0.91 (0.0)	→	0.50 (77.3)	0.40 (84.9)	no lags	0.61 (69.3)
1987	Granger	6.68 (0.0)	↔	3.42 (0.5)	7.63 (0.0)	→ ↜	2.47 (3.4)	3.32 (6.6)	?↝	1.46 (20.1)
	Geweke	5.40 (0.0)	→ ↜	3.02 (1.2)	5.82 (0.0)	→	1.69 (13.8)	3.86 (2.4)	↝	2.08 (7.1)
1988	Granger	3.07 (1.1)	→	1.38 (23.4)	2.48 (3.3)	⟷	2.96 (1.3)	1.53 (18.4)	←	4.58 (0.1)
	Geweke	3.48 (0.5)	→	1.36 (24.3)	2.05 (7.3)	↜	2.90 (1.5)	0.54 (74.5)	←	4.43 (0.1)
1983-88	Granger	17.3 (0.0)	↔	4.55 (0.0)	26.85 (0.0)	→	0.87 (50.1)	8.63 (0.0)	↔	3.06 (0.1)
	Geweke	14.17 (0.0)	↔	4.87 (0.0)	23.45 (0.0)	→	1.12 (34.9)	6.67 (0.0)	↔	4.08 (0.1)

Table 4.1: Naive Hedging Efficiency in the Forward & Futures Market ($/tonne)

	STANDARD ERROR		VARIANCE		HEDGE EFFICIENCY
	BASIS	SPOT	BASIS	SPOT	
1. Direct Hedges					
Forward Market - 85	1.90	3.06	3.61	9.39	0.62
- 86	5.00	5.45	25.05	29.70	0.16
- 87	1.18	2.58	1.40	6.65	0.79
- 88	1.14	2.26	1.31	5.11	0.74
Futures Market - 85	2.15	2.68	4.63	7.20	0.36
- 86	4.54	4.31	20.65	18.53	-0.11
- 87	1.61	2.62	2.58	6.89	0.63
- 88	1.35	2.41	1.82	5.80	0.69
2. Cross Hedges					
Forward Market - 85	1.81	2.68	3.27	7.20	0.55
- 86	4.61	4.31	21.24	18.53	-0.15
- 87	1.58	2.62	2.48	6.89	0.64
- 88	1.34	2.41	1.79	5.80	0.69
Futures Market - 85	2.33	3.06	5.43	9.39	0.42
- 86	4.90	5.45	24.04	29.70	0.19
- 87	1.44	2.58	2.06	6.65	0.69
- 88	1.25	2.26	1.57	5.11	0.69

Table 4.2: Hedge Ratios and Hedging Efficiency in the Forward & Futures Markets.

Results of OLS Regressions using Price Levels: 1985-88, 1987-88.

$SP_t = a + bFP_t$

	INTERCEPT	HEDGE RATIO	HEDGING EFFICIENCY		STATISTICS	
	a(t-stat)	b(t-stat)	R^2	SEE	DWS	OBS
1. Direct Hedges						
Forward Market - 85/88	-3.280 (4.46)	1.029 (232.62)	0.9831	5.83	0.26	932
- 87/88	0.570 (0.74)	0.996 (187.75)	0.9859	1.811	0.44	505
Futures Market - 85/88	-3.902 (3.68)	1.044 (163.94)	0.9664	8.371	0.11	932
- 87/88	-0.776 (0.77)	1.010 (144.96)	0.9767	2.353	0.40	503
2. Cross Hedges						
Forward Market - 85/88	-2.520 (2.49)	1.033 (170.31)	0.9689	8.036	0.12	932
- 87/88	0.147 (0.16)	1.002 (154.81)	0.9794	2.209	0.47	505
Futures Market - 85/88	-4.675 (5.88)	1.040 (217.42)	0.9806	6.252	0.23	932
- 87/88	-0.109 (0.12)	1.003 (157.20)	0.9801	2.153	0.40	503

Table 4.3: Hedge Ratios and Hedging Efficiency in the Forward & Futures Markets.

Results of OLS Regressions using Price Changes: 1985-88, 1987-88

$$\Delta SP_t = a + b\Delta FP_t$$

	INTERCEPT	HEDGE RATIO	HEDGING EFFICIENCY		STATISTICS	
	a(t-stat)	b(t-stat)	R^2	SEE	DWS	OBS
1. Direct Hedges						
Forward Market - 85/88	-0.041 (0.49)	0.653 (30.15)	0.5038	2.496	2.31	897
- 87/88	-0.011 (0.22)	0.866 (42.78)	0.7885	1.115	2.50	493
Futures Market - 85/88	0.008 (0.09)	0.803 (28.18)	0.4677	2.673	2.45	904
- 87/88	-0.012 (0.19)	0.839 (32.34)	0.6818	1.427	2.76	490
2. Cross Hedges						
Forward Market - 85/88	-0.013 (0.18)	0.576 (30.28)	0.5055	2.172	2.35	897
- 87/88	-0.020 (0.31)	0.843 (32.99)	0.6890	1.407	2.75	493
Futures Market - 85/88	-0.048 (0.55)	0.663 (28.26)	0.4696	2.616	2.38	904
- 87/88	-0.002 (0.04)	0.831 (35.75)	0.7237	1.278	2.51	490

APPENDIX 4

FIGURES

Figure 2.1: Spot, Forward & Futures Prices: 1983-88

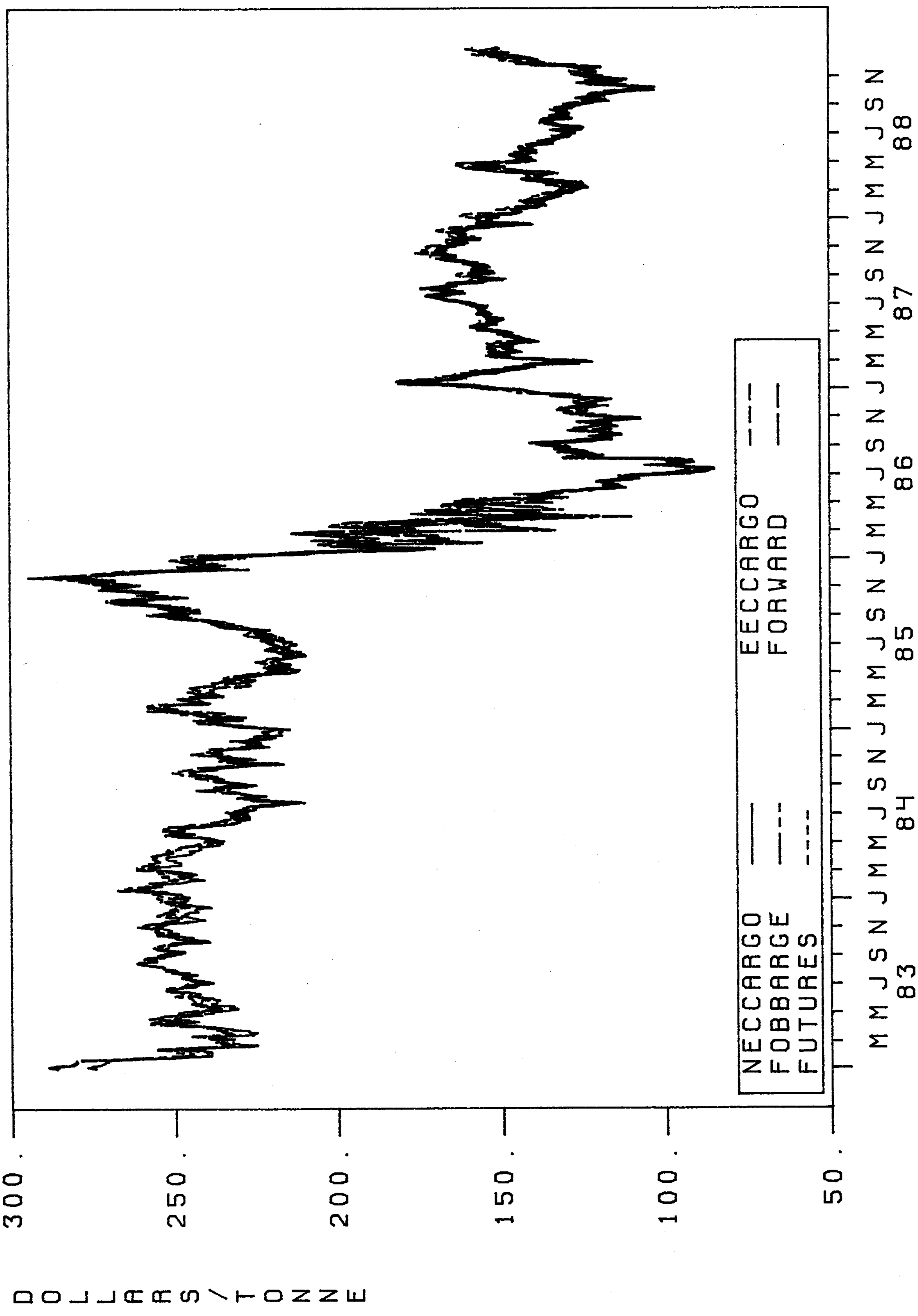


Figure 2.2: Seasonal Patterns: Spot Price Ratios, 1983-88

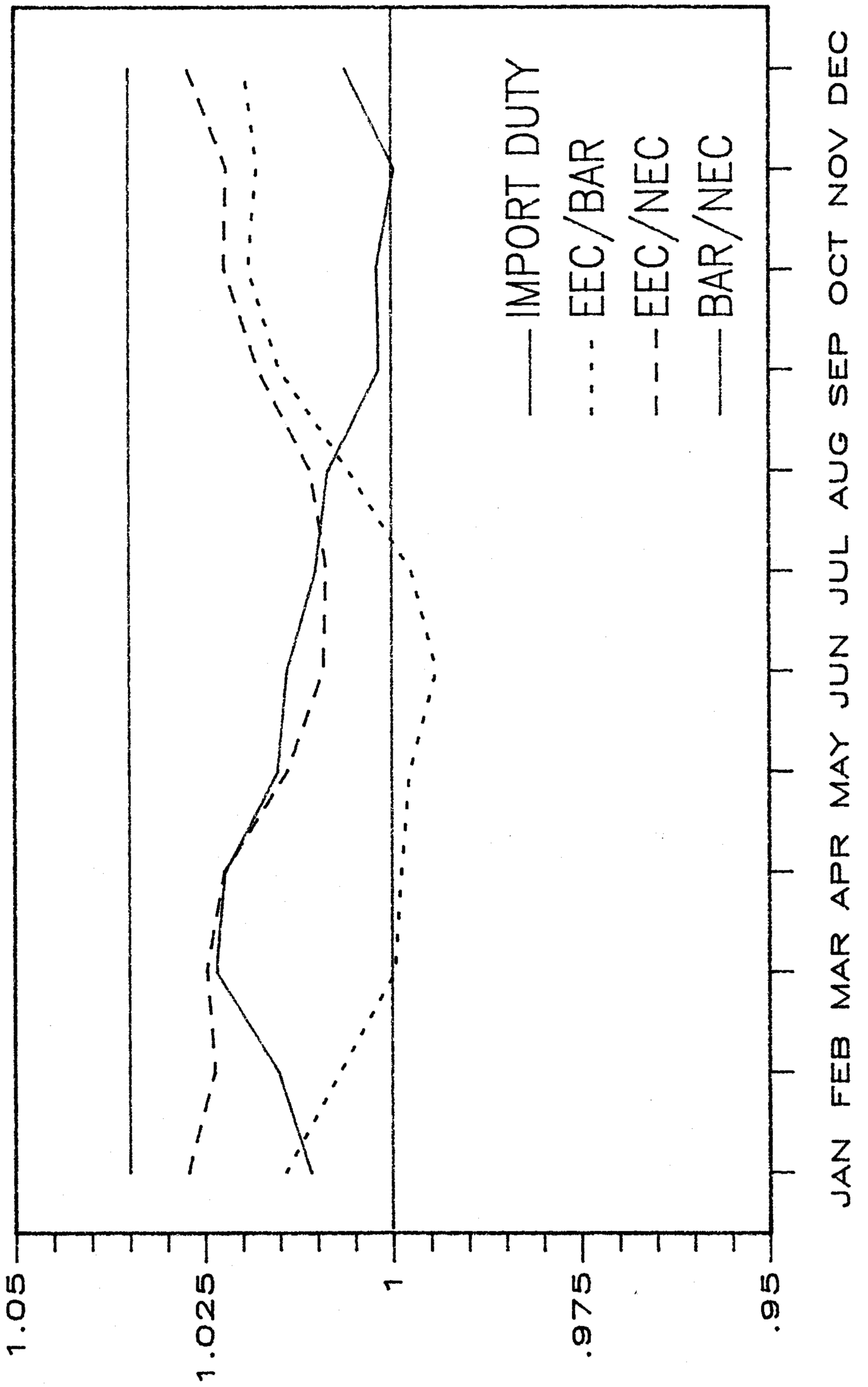


Figure 2.3: Seasonal Patterns: Average End-Month ARA Gas Oil Stocks, 1987-89

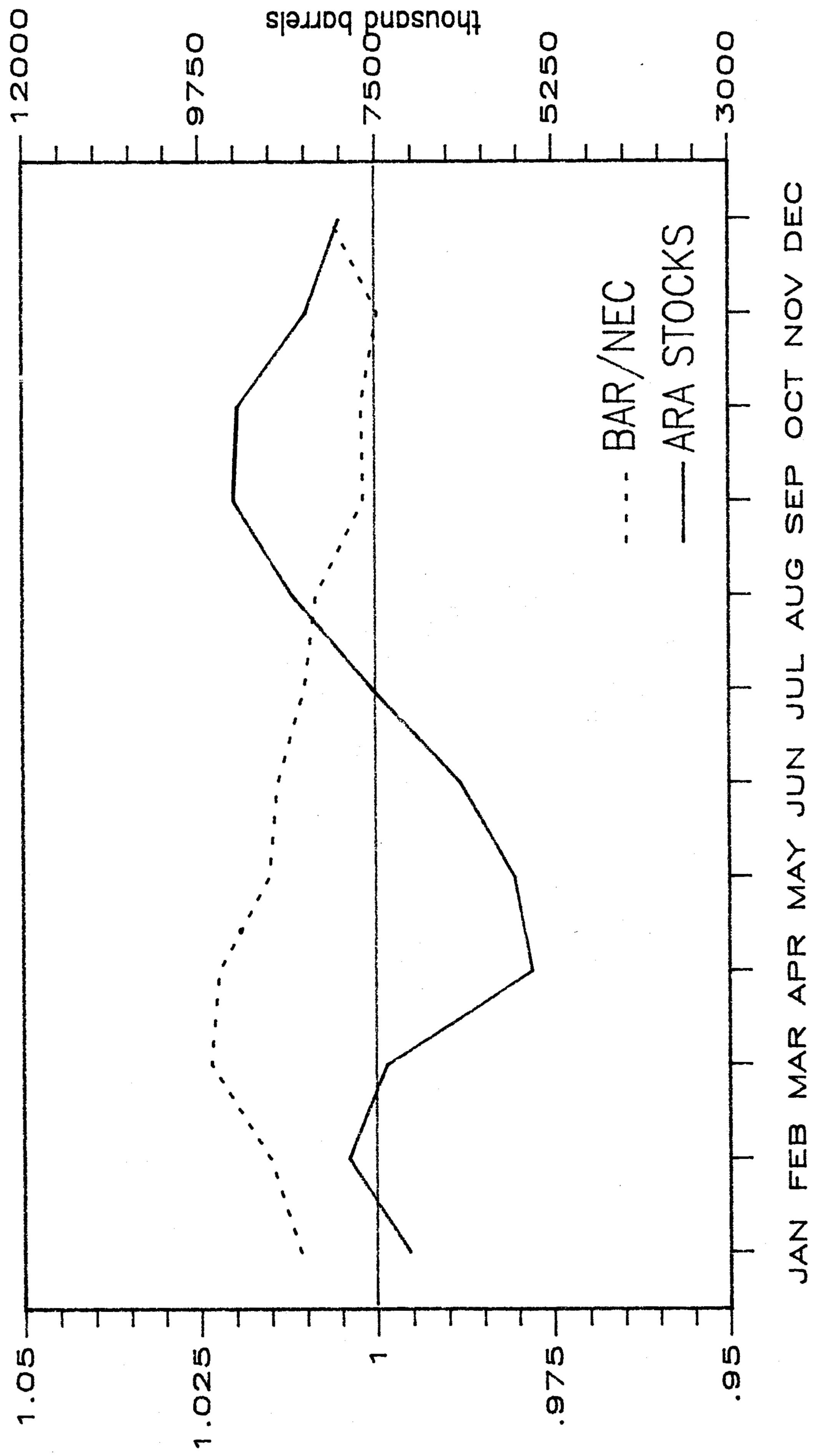


Figure 2.4: Seasonal Patterns: Spot:Forward & Spot:Futures Price Ratios, 1987-88

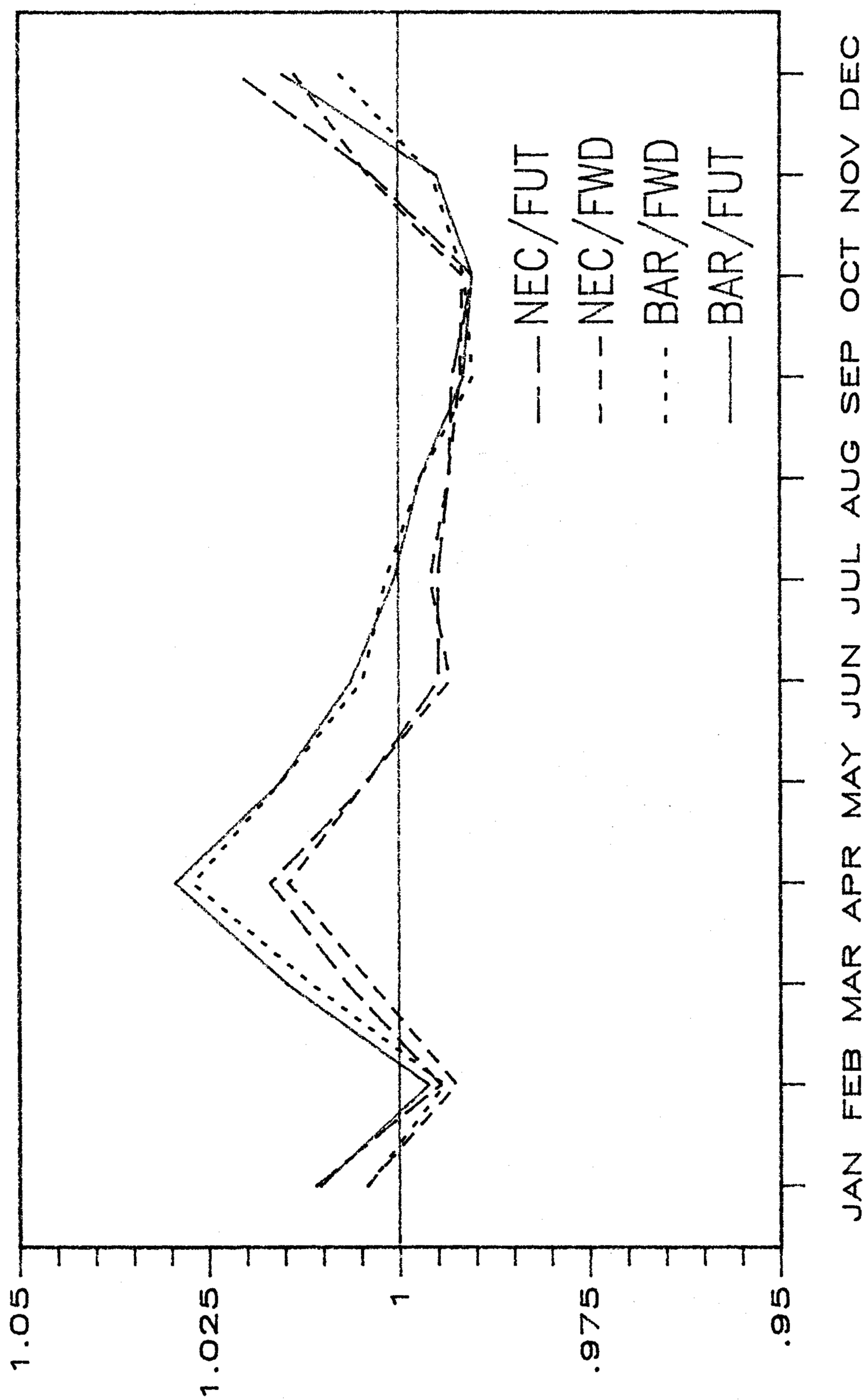


Figure 2.5: Price Ratios: Barge:Non-EEC Cargo Prices, 1983-88

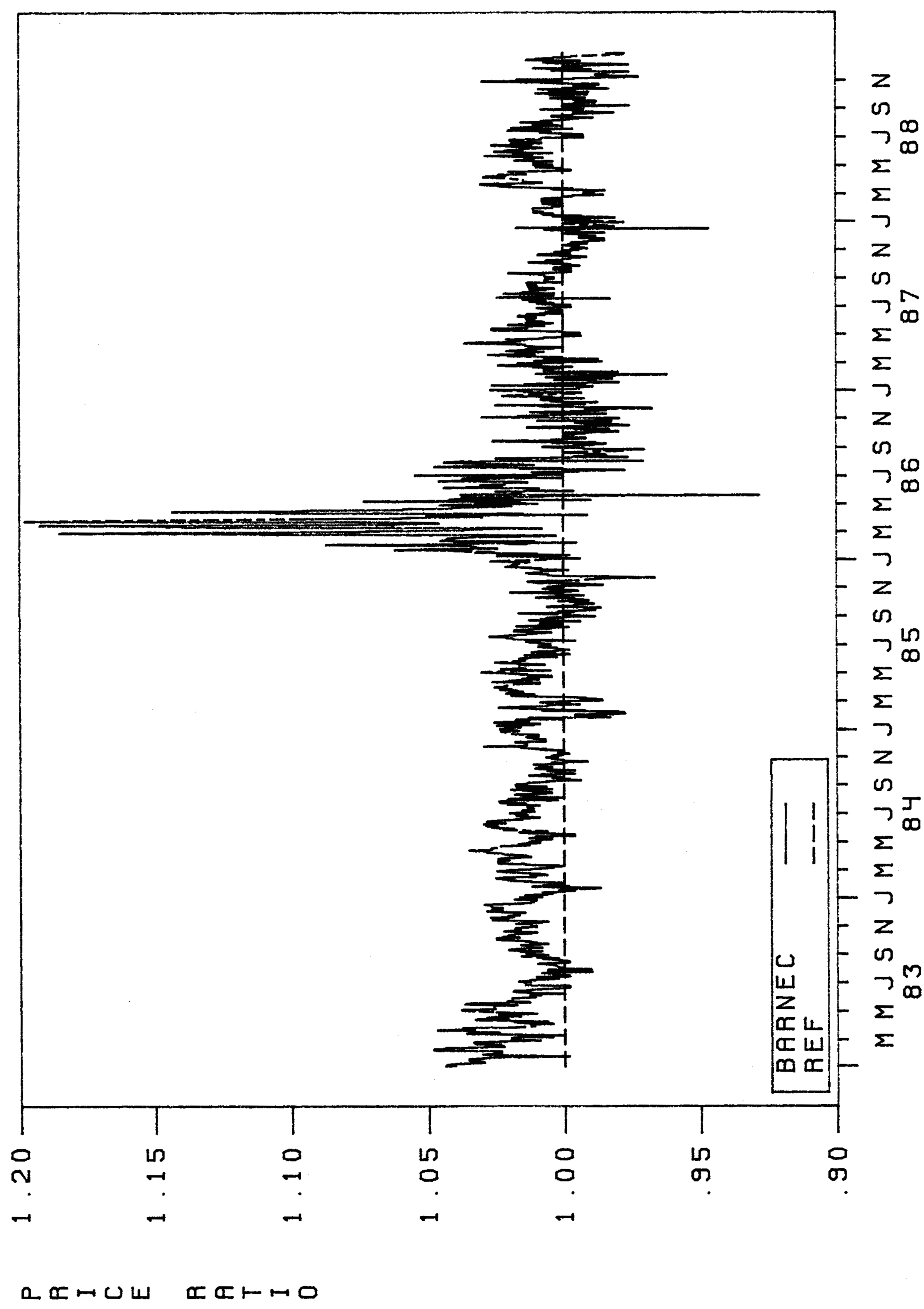


Figure 2.6: Price Ratios: Barge:EEC Cargo Prices, 1983-88

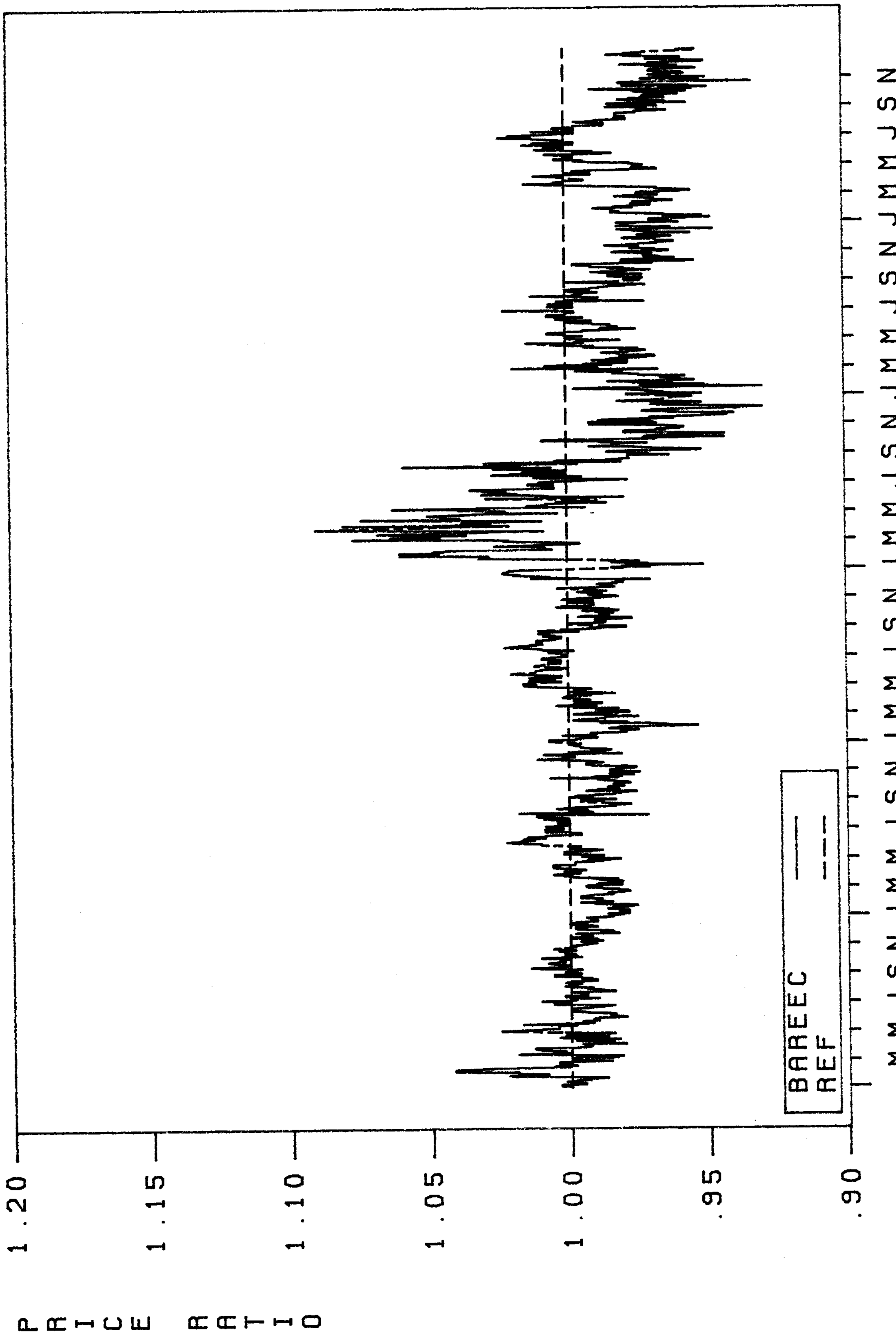


Figure 2.7: Price Ratios: EEC Cargo:Non-EEC Cargo Prices, 1983-88

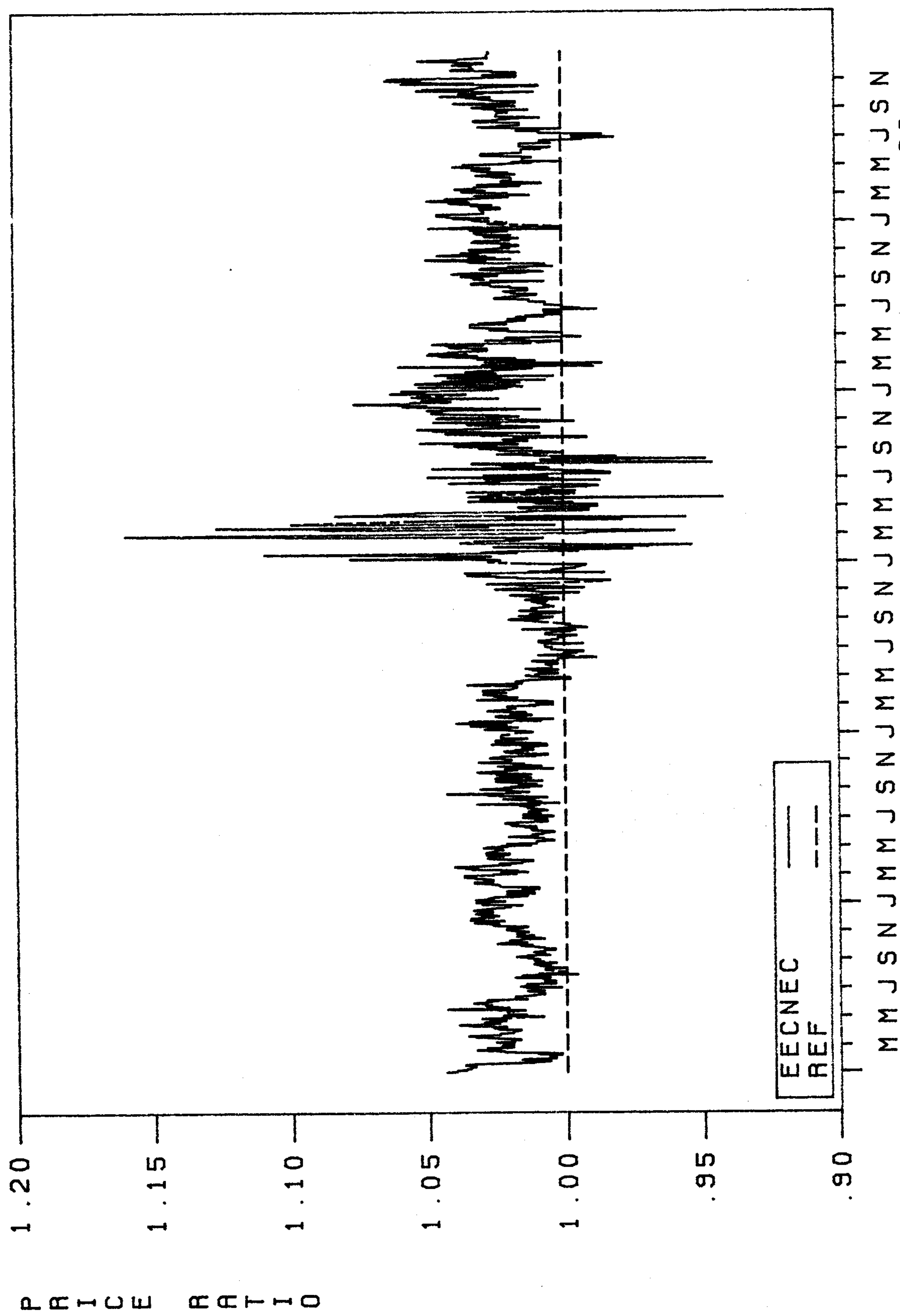


Figure 2.8:   Price Ratios: Forward Russian:IPE Futures, 1985-88

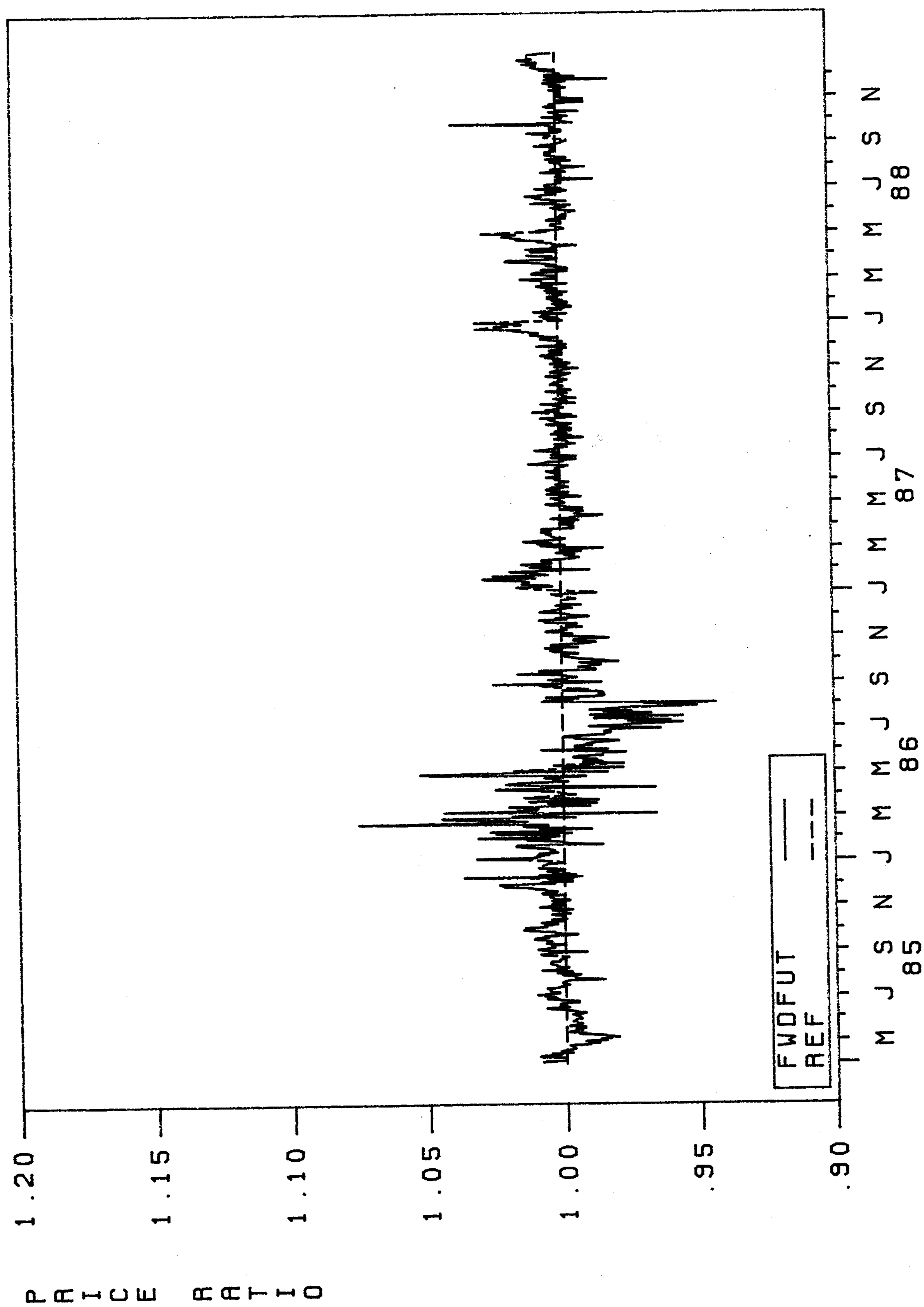


Figure 2.9: Price Ratios: Non-EEC Cargoes:Forward Russian, 1985-88

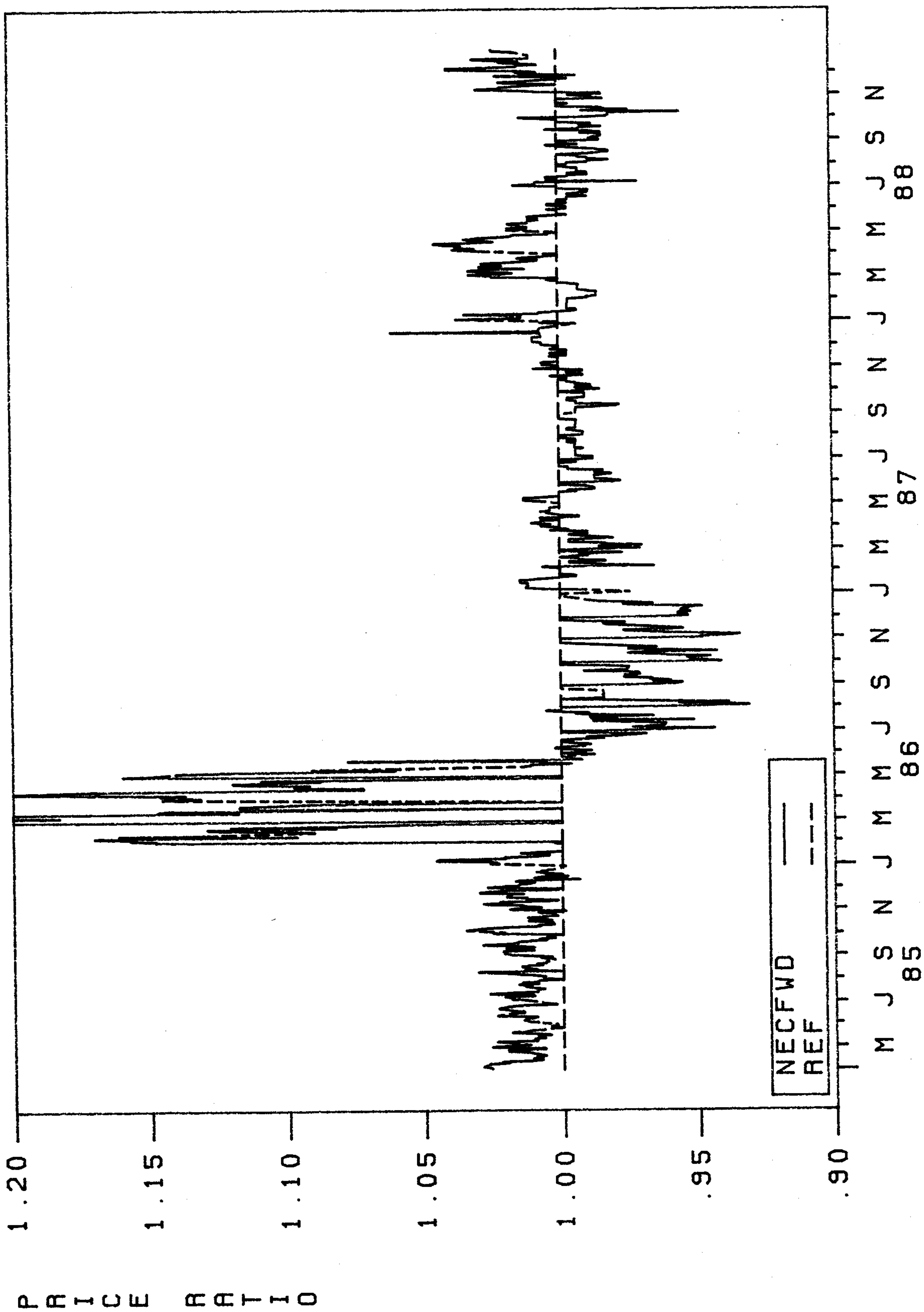


Figure 2.10: Price Ratios: Barges:IPE Futures, 1985-88

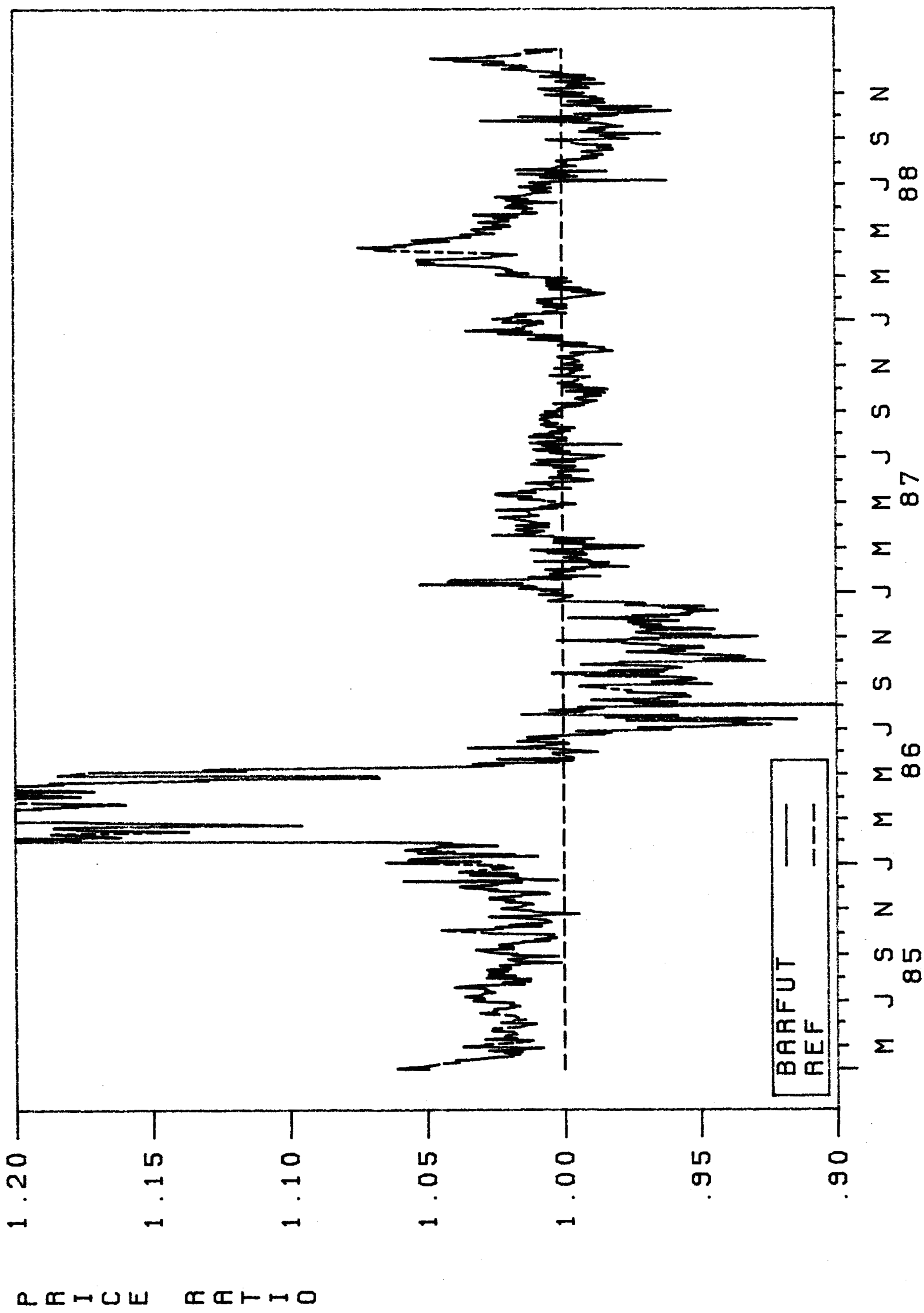


Figure 3.1: Daily Returns: fob Barges, 1983-88

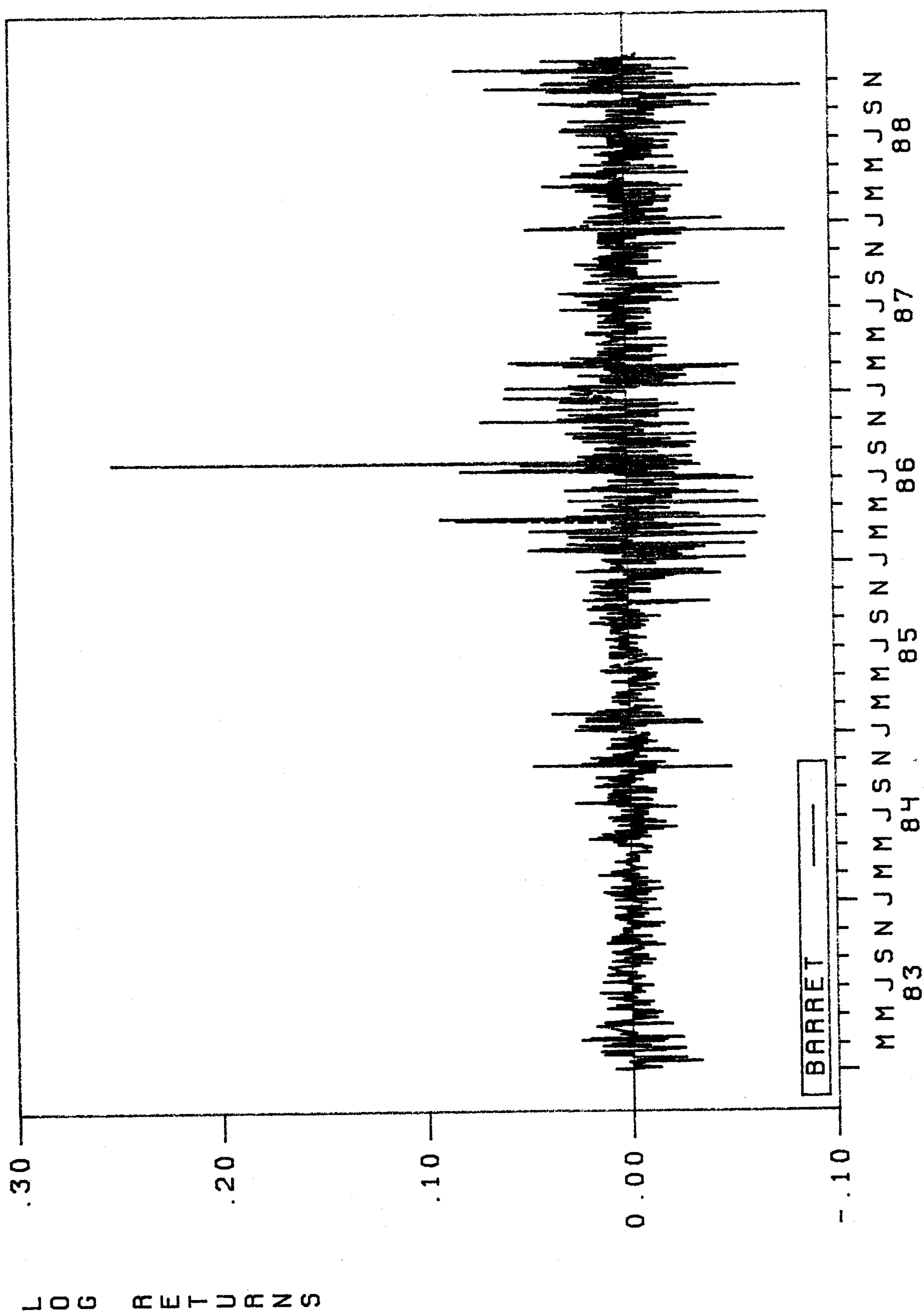


Figure 3.2: Daily Returns: Forward Russian, 1985-88

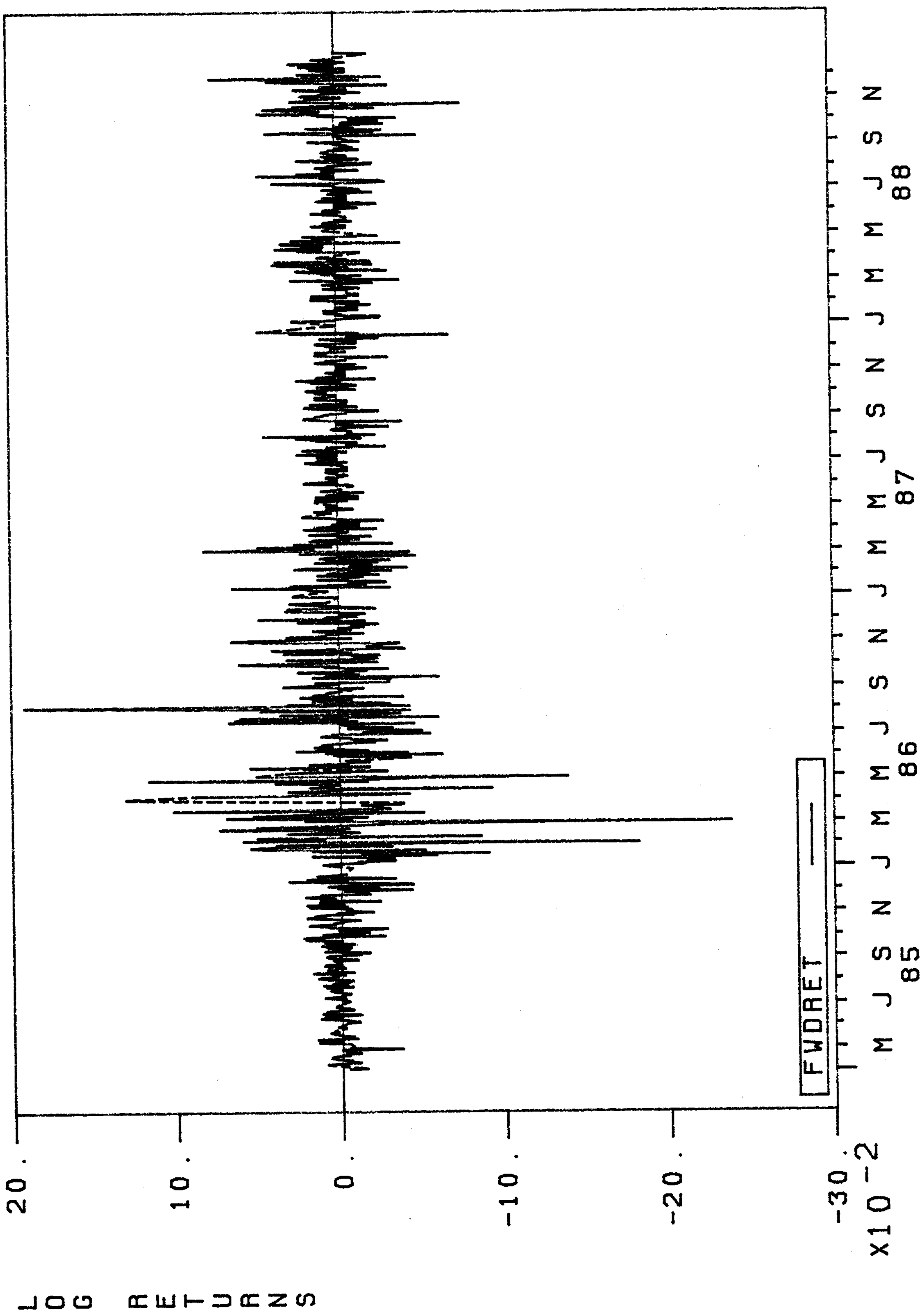


Figure 3.3: Daily Returns: IPE Futures, 1985-88

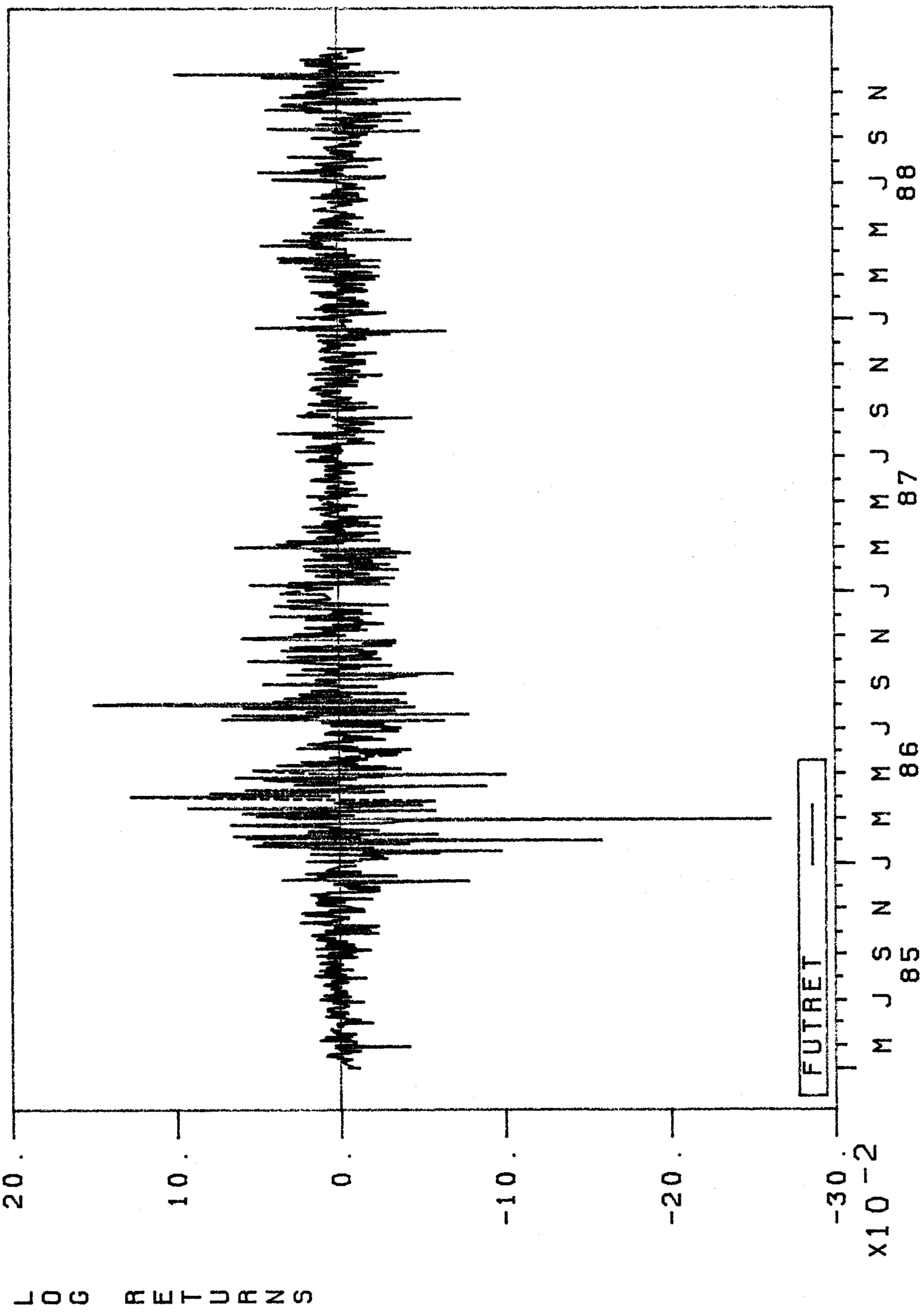


Figure 3.4: Daily Returns: Annualised Volatility, Spot Non-EEC Cargoes 1983-85

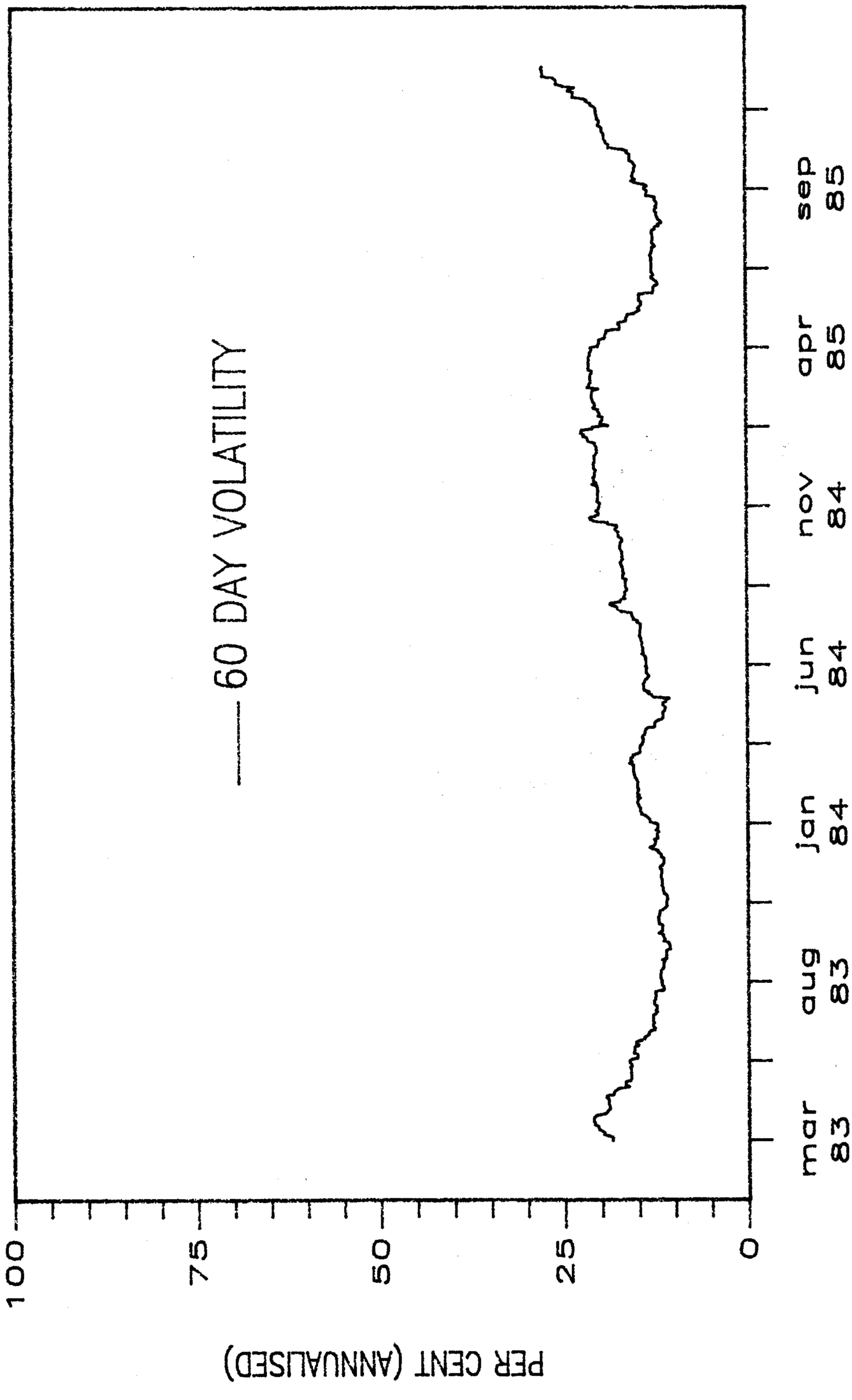
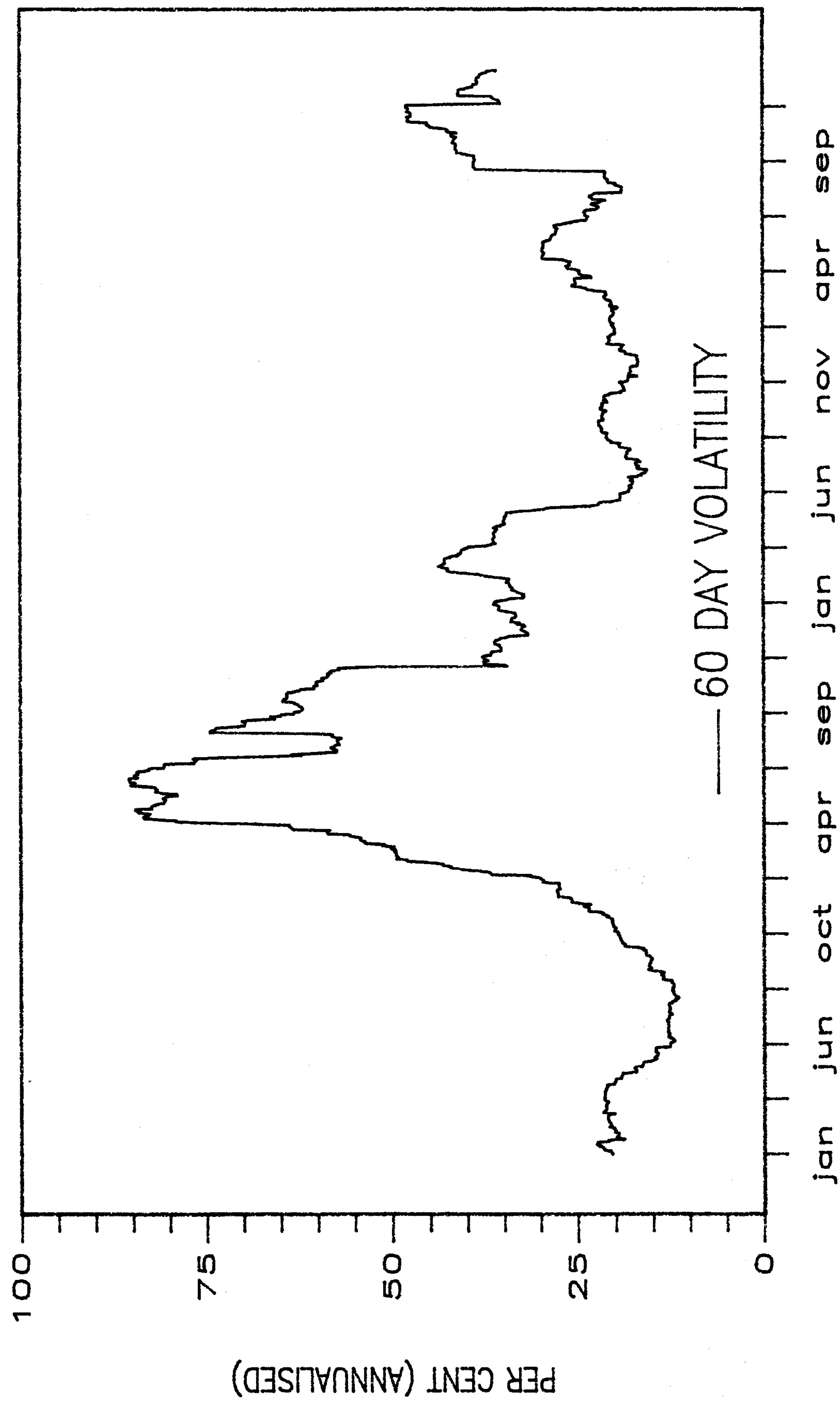


Figure 3.5: Daily Returns: Annualised Volatility, Spot Non-EEC Cargoes 1985-88



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