Information, Volatility and Price Discovery in Oil Futures Markets

by

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"Whosoever loveth wisdom is righteous but he that keepeth company with fowl is weird."

Woody Allen (1978)

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ABSTRACT

This thesis presents four related empirical essays which investigate the role of information in crude oil futures markets. The first line of investigation examines the impact of futures trading on spot price volatility and finds that the nature of spot price volatility is affected by derivative trading and the improvements in information discovery which such trading brings. Second, the efficiency of futures markets is examined with respect to their ability to provide unbiased estimates of future spot prices. Here it is concluded that while unbiased estimates are generally provided in the long-term, they tend to be largely biased over the short-term. The third area of investigation looks at the relative ability of contemporaneous spot and futures prices to discover information, where it is found that futures generally exhibit price discovery over spot markets but that the relationship can vary considerably over time and in relation to market conditions. In addition, the investigation suggests that previous studies into such relationships have failed to account for all routes through which information passes between spot and futures markets. Finally the thesis probes the question of the relationship within futures markets between volume, volatility and information. The finding is that futures markets' prices and trading volume exhibit a positive relation and are jointly driven by the rate of information arrival. The results further suggest that the widely held expectation that volume statistics can improve forecasts of future price change does not hold in the case of oil futures. The overall finding of the thesis is that oil futures markets are well-functioning and in general are of benefit to the underlying spot market.

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INTRODUCTION

The benefits attributed to derivative instruments such as futures contracts include: the expansion of the information set available to market agents, leading to enhanced price discovery on both inter-temporal and contemporaneous bases; the completion of otherwise incomplete markets through the provision of additional state contingent payoffs; and the provision of hedging opportunities, with speculative opportunities arising as a consequence.

The provision of hedging opportunities is arguably the most important aspect of futures trading, but for this feature to be successfully provided, the informational role of futures must be satisfied. The expansion and improvement of the information set available to market participants is central to the notion of derivative instruments fulfilling their prescribed roles. If derivative trading promotes the identification, transmission and incorporation of information, then its presence is expected to be manifest in the response of actuals' prices to information. As such, the effect of futures trading on the underlying market for actuals will be positive. Should the presence of derivatives lead to the transmission of noise rather than information, however, then their impact on the underlying market will be negative. If derivative markets do contain excessive noise then its transmission into actuals' prices under the guise of information, will lead to price distortions in the latter market.

Futures markets can be expected to play a beneficial economic role only if they successfully carry out their prescribed functions. In the case where futures accentuate noise transference, where they give misleading signals as to future demand and supply conditions, and where they bring unnecessary price volatility, there is an argument for their termination. An examination of the functioning of futures markets is thus of considerable interest to academics, policy-makers and practitioners alike.

Given its pre-eminence amongst commodities it is somewhat surprising that the functioning of oil futures markets have received so little attention to date. The vast majority of studies into the workings and performance of commodity futures markets have concentrated on agricultural products. Furthermore, most studies have focused their attention on the experience of futures markets in the US. This thesis aims to provide a detailed analysis of the functioning of crude oil futures markets and their relationship with the underlying spot commodity. Moreover, the thesis extends the methodologies used in such studies. The subject matter of the investigations undertaken in this thesis is the futures market for crude oil, the world's largest traded commodity. In studying oil futures markets, however, this thesis looks not only at the UK, but also oil futures in the US. Evidence is presented for the UK's Brent crude oil futures market, and the US' West Texas Intermediate crude oil futures market.

This thesis presents four related empirical essays which examine issues of interest to futures market participants and policy-makers: the effect of futures trading on the nature and magnitude of spot price volatility; the efficiency of futures markets in terms of their ability to provide optimal predictions of future spot prices; price dominance between spot and futures markets; and finally the relationship between information, volatility and volume in futures markets. The common theme of these chapters relates to information in futures markets and how that information affects the futures market itself and the underlying spot market upon which the futures market is based.

Chapter 1 describes the international market for crude oil and its underlying futures market as a foundation to the ensuing economic investigations. This chapter outlines the growth of the spot market as the main arena for trading crude oil and the development of futures contracts to support the spot market. In addition this chapter reviews the literature relevant to the studies undertaken here.

Chapter 2 investigates the possible effects on spot price volatility due to the introduction of a corresponding futures contract. Using the GARCH family of statistical models volatility is examined for both weekly and daily prices. For the purpose of comparison with the results generated by previous studies, preliminary investigation adopts regression techniques. This practice also serves to highlight the advantages of using the more relevant GARCH procedure. The main emphasis of the investigation remains, however, with the use of GARCH to model volatility, a practice which constitutes the main contribution of the investigation. The main findings are that the degree of persistence of volatility in the spot market has fallen, and that the nature of volatility has changed since the onset of derivative trading. The investigation is also novel in that it attempts to separate noise volatility from information volatility using the Kalman filter. The investigation is restricted to the case of Brent crude oil since appropriate data for WTI crude is not available.

Chapter 3 uses recent developments in cointegration theory to explore efficiency in crude oil futures markets with respect to their ability to serve as unbiased predictors of future spot prices. This is achieved by testing the joint assumption that market agents are risk neutral and use all available information rationally. Findings show that results from cointegrating regressions may falsely lead to the acceptance of efficiency by ignoring short-term dynamics. This necessitates the use of error-correction models in testing efficiency, a practice not yet widely adopted by the current literature. Results support market efficiency in the long-term for WTI crude oil futures for at least 3 months to maturity, but reject long-term efficiency for Brent crude for all maturities considered. Examination of the error-correction models for WTI crude suggest that the market is efficient in the short-term for the one-month contract only.

Chapter 4 provides a re-examination of price dominance between spot and futures markets and proposes that previous work has not fully accounted for the routes through which information is transmitted between those markets. Preliminary investigation uses the theory of cointegration to establish a relationship between spot and futures markets. From the cointegrating relationship the implied error-correction model is specified and used to identify all the channels through which information is transmitted. This model is shown to represent a synthesis of the commonly used Garbade and Silber, and Granger causality models for exploring dominance relationships and hence offers a methodological extension to study in this field. Furthermore, it is proposed that standard point estimation fails to take proper account of the temporal nature of dominance relationships. As a response the Kalman Filter is employed to estimate time-varying dominance. The results from this analysis show dominance relationships to be changeable over time, while supporting a general conclusion of futures markets dominating spot markets.

Chapter 5 addresses the relationship between trading volume and price variability in futures. Here we examine the connection between price volatility, trading volume and the flow of information. The investigation begins by examining empirical regularities between volume and price change variables. Results support the common expectation of a positive correlation between the magnitude of trading volume and the dispersion of price change. Moreover, it is found that the price-variability-volume relation is symmetric with price rises being accompanied by broadly similar trading volumes to price falls. The study proceeds to more rigorous analysis which involves the use of GARCH to test the view that volume can be used as a proxy for the rate of information arrival, and the GMM technique to test for a contemporaneous relation for volume and volatility driven by common reactions to the flow of information. Overall the results support the notion that price variability and trading volume represent a mixture of distributions where the directing variable is the rate of flow of information

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Chapter 6 concludes the thesis by providing a summary of the work undertaken and by suggesting policy implications of those results. In addition, the chapter identifies a number of issues that merit further investigation.

CHAPTER 1

THE ECONOMICS OF CRUDE OIL FUTURES

I THE INTERNATIONAL OIL MARKET

I 1.1 INTRODUCTION

This section presents a background to the oil industry and its futures markets. An understanding of the environment in which oil futures markets operate and the way in which they operate is a prerequisite to a proper appreciation of the subject matter of this study. This section provides an understanding of the nature of oil itself, the structure and a brief history of the industry which has developed around it, and the development and functioning of crude oil futures markets.

As the world's largest traded commodity, in terms of both value and volume, the oil market is of great interest. The importance of oil in both economic and political spheres is well known. Oil is a central feature of many modern economies - it is the lifeblood of most industrial activity - and the trade in crude oil and crude distillates represents a substantial share of world trade. World production figures for crude oil are presented in Table 1.1 below.

The dependence of industrialized nations on oil as a source of energy and as a raw material for the petrochemical industry means that the price of oil has a significant influence on their economic prosperity. The eudaemonic significance of oil to industrialized economies assures us of its continued political as well as economic importance. The political aspects of oil play their role not only in industrialized nations but also between those nations and the oil producing countries.

The oil price shocks of 1973/74 and 1979, and the Gulf conflict of 1990/91 have served to highlight the dependence of industrialized economies on oil and the concern that threat of price rise or discontinuation of supply can cause. The considerable redistributive effects of oil price hikes, and the readiness of interested parties on both sides of the oil trade to 'encourage' oil prices and output levels in accordance with their own self-interests has led to the politicization of the commodity market.

This section elaborates on the history and significance of oil and proceeds as follows. First we consider the nature of oil and its physical derivatives, we then trace the development of the modern international oil market and in so doing illustrate the current market state. Attention is then turned to the growth of the spot market as the main medium for the physical trade of oil. Finally the section considers the development of futures markets for crude oil.

I 1.2 Crude Oil and Oil Products

Crude oil is a flammable liquid found in subterranean deposits. Chemically it is a complex mixture of hydrocarbons; compounds of hydrogen and carbon molecules. In addition sulphur, nitrogen, oxygen and some metallic elements also appear in small quantities. Crude itself is not a homogeneous substance; there are a number of different types of crude oil each distinguishable by distillate and sulphur content.

Table 1.1

World Production of Crude Oil

Area Key producer	Production (Thousand metric tons)				
	1982	1984	1986	1988	1990
Africa	**216 708**	**230 025**	**239 605**	**243 715**	**294 808**
Nigeria	63 630	69 340	72 805	67 735	86 538
America, North	**640 574**	**658 593**	**636 646**	**629 449**	**558 065**
United States	425 591	438 127	428 154	410 637	369 679
America, South	**169 520**	**176 741**	**186 275**	**195 509**	**214 486**
Venezuela	100 391	94 850	93 933	100 120	112 009
Asia	**855 791**	**784 590**	**879 377**	**988 480**	**1 117 685**
Saudi Arabia	323 345	204 180	238 460	253 520	320 375
Europe, West	**139 599**	**173 646**	**183 742**	**189 622**	**191 164**
United Kingdom	100 311	121 306	121 238	109 455	88 010
Europe, East	**18 456**	**16 922**	**15 572**	**14 755**	**13 185**
Romania	11 742	11 453	10 125	9 389	7 929
Former USSR	**612 551**	**607 000**	**609 700**	**617 400**	**565 500**
Oceania	**18 682**	**21 397**	**27 014**	**26 567**	**27 238**
Australia	18 034	20 586	25 282	25 056	25 502

Source: Industrial Statistics Yearbook (1992), United Nations.

Distillate content, along with method of refinement, determines the quantity and quality of products that can be obtained from a particular crude oil.

Crude oil is typically described with reference to three variables; field of origin, API gravity, and sulphur content. The field of origin is the most important of the three descriptive variables since it gives an indication of a number of characteristics particular to crudes from that field.[1] A crude's API gravity indicates the quantity of different products which it will yield. A crude with a low API gravity is a 'heavy' i.e. dense oil and will produce larger quantities of heavy products such as residual fuel oil. High API gravity crudes conversely, offer larger yields of lighter products such as gasoline. Light crudes have an API gravity in excess of 35° while heavy crudes have an API gravity below 24°.

The sulphur content of oil is used as a guide to its purity; high sulphur crudes (more than 0.5%) are described as 'sour' while low sulphur crudes (less than 0.5% sulphur) are 'sweet'. Sulphur poses problems for refining, and as a consequence sweet crudes invariably trade at a premium to sour crudes.

Crude oil is rarely used in its raw state but is subjected to a series of refining processes such as fractional distillation, thermal cracking, catalytic cracking and polymerization. Refining produces a number of different energy products in addition to raw materials (feedstocks) for the petrochemical industry, used for the production

[1] A field will produce crude oils which, in general, have their own characteristics. These include; distillation yields, viscosity, and water and metallic contaminant content. Such characteristics will differ across fields. See Glossary for an explanation of terms used.

of plastics, solvents, and synthetic elastomers. While refining techniques vary they are all based on the same basic distillation process. This involves heating crude oil and feeding it into a fractioning column where it is separated into different products depending upon their boiling range.[2]

Different refining techniques are suited to different types of crude and yield different combinations of derivatives. The nature of crude itself can vary greatly in colour, density and viscosity and depending upon the nature of the hydrocarbons is categorised as paraffinic, napthinic or aromatic. Simple hydrocarbon molecules contain a small number of carbon atoms and a relatively larger number of hydrogen atoms and produce gases and light liquid distillates. More complex hydrocarbon atoms contain more carbon atoms and fewer hydrogen atoms with their distillates being heavy, viscous liquids or even solids. Crude oil can be refined to give a multitude of distillates and these derivatives can be categorized by their membership to one of six major groups of products, although membership is not always exact.

Hydrocarbon gases form the first group of oil distillates and include liquefied gases, petroleum ether, polymers (from which lubricating oils are made), alcohols (for solvents), acetylene, fuel gas and light napthas (pentane & hexane). Light distillates represent the second group of derivatives and include two subgroups; napthas and refined oils. Intermediate napthas are used for aviation fuel, petrol (gasoline), and commercial solvents, while heavy napthas produce turpentine substitutes. Refined oils

[2] For detailed technical descriptions of refining processes see Ellis-Jones (1988) chapter 9, and Hirschfeld (1983).

include kerosene and signal oils. The third group, intermediate distillates, comprise of gasoil and absorber oil. Gasoil is used for diesel oil and space heating as well as being a feedstock for the chemical industry. The next group of distillates are the heavy distillates of which there are four main types; technical oils, paraffin wax, lubricating oils, and petroleum grease. Residual products form the fifth group of crude derivatives and consist of residual fuel oils (such as boiler oils), still wax, asphalts and coke. Finally there are refinery sludges; heavy fuel oil, sulphuric acid, and acid coke which are classed as waste products (although sulphuric acid may be used to make fertilizers).

I 1.3 Oil Production

The Multinational Oil Firms

The multinational firms or 'majors' are very large vertically integrated companies whose presence in the oil industry was once dominant but has been considerably lessened particularly in upstream production (mining) with the nationalisation of oil fields and the emergence of state owned oil companies/producer nations. Prior to the early 1970s the seven majors[3] held the production rights to more than 60% of non-communist crude oil, and fixed the contract prices at which oil was sold. The development of the multinational oil firms in the first half of this century represents the first phase in the evolution of the international oil industry. Before the rise of the majors the oil industry was characterized by a number of small producers, refiners and marketers, but towards the end of the Nineteenth Century it came to be dominated by

[3] The seven majors are BP, Exxon, Gulf, Mobil, Royal/Dutch Shell, Socal (Standard Oil of California), and Texaco

a few large multinational firms.

Initially the majors confined themselves to their own geographic areas of interest; either domestic sources, such as Standard Oil's dominance of the US market, or colonial areas such as British interests in India through the Burmah Oil Co, and Holland's Royal Dutch interests in the East Indies. Once such companies had emerged they began to integrate both upstream and downstream. It was the interest in upstream integration which led to the majors' involvement in the Middle East, an area of substantial oil reserves. The first oil concession obtained in the Middle East was granted in 1901 and began a "scramble for oil concessions" in the area with European and (post 1920) American interests trying to gain rights to the vast Middle East reserves.

By the late 1920s the majors had achieved such a position in the Middle East that an oil glut and associated price fall were becoming increasingly likely, a situation which led to the signing in 1928 of the Red Line Agreement. This agreement effectively removed competition between the majors, and together with later agreements such as the 1928 Achnacarry Agreement which allocated production rights and market shares, signified the majors' control over the international oil market and their intention to hinder competition and preserve markets. The effect of this was that by the late 1930s control over Middle East oil production and marketing had been firmly established by the seven major oil companies which dominated all aspects of the oil industry.

This dominant position was consolidated during the 1940s and 1950s as the post war increases in demand for oil and the opportunities to secure oil concessions in newly decolonialized countries gave the majors opportunities to expand and increase their influence in the world oil market. By the late 1950s, however, the majors began to lose influence as their high profits encouraged smaller 'independents' to enter the market, while concessions from newly independent countries such as Libya became available. The combination of new prospective sources of oil and companies willing to bring that oil to market led to an increase in world oil production. As prices fell the majors began to lose power. It was in this phase of the industry's evolution that the now producer nations began progressively to nationalise the majors' oil concessions.

The Producer Nations

As intimated above, control of the international oil industry was wrested from the multinationals by the now producer nations. The large scale production of crude oil has centred around various different locations throughout the history of the international oil market. Initial production was located in the US and Russia/Rumania which, by the end of the Nineteenth Century, produced about 90% of world oil. During the 1940s and 1950s the Middle East became the primary source of internationally traded crude (as distinct from total world output) and while new sources have been found in the latter half of this century - notably the North Sea, Alaska and Mexico - the world's dependence on Middle East oil is still substantial; the annual output of crude from Saudi Arabia, Iran, Iraq, Kuwait and UAE represents approximately 20% of total world production.

The process which led to a shift in ownership from the majors to the producer nations began in 1943 when Venezuela raised royalties paid by the majors to 16.7%. In 1948 the distribution of wealth was further shifted from company to nation when Venezuela introduced a 50% tax on oil company profits, and to prevent Venezuelan crude from becoming uncompetitive, encouraged the main Middle East producers to follow suit. By 1951 variations on the fifty-fifty profit-sharing agreement had been adopted by all Middle East producers.

Despite their concessions over profits the majors retained their dominant position in the oil market. This was demonstrated in 1951 when a tide of nationalist spirit in Iran led to the Anglo-Iranian Oil Co (later to become BP) being nationalised by Mohammed Mossadegh. The ensuing boycott of the newly formed Iranian National Oil Company by the majors had the effect of cutting Iran's oil exports from their $400m 1950 level to an average of only $1m per year until the Shah's reinstatement in 1953.

It was the emergence of the independents and several state owned oil companies which promoted the final shift of power in the production of oil from the international companies to the oil-endowed nations, breaking the majors' monopoly. As newly independent countries sought foreign investment to develop their oil reserves, the number of independents in search of oil concessions grew, satisfying a coincidence of wants which led to increased oil production. As world production increased the 1950s closed with a glut in the oil market, to which the majors responded by cutting prices in 1959 and again in 1960. Facing large losses in revenues as a result of declining prices, Saudi Arabia, Iran, Iraq, Kuwait and Venezuela met in 1960 to discuss the state of the oil market; a meeting which resulted in the creation of OPEC.

The creation of OPEC was not, however, purely a reaction to falling prices, but was also a response to the fact that the majors had determined the price of oil without consulting the producer nations. Realization was growing amongst producer nations that they did not have sovereignty over their own oil endowments so long as they were divorced from pricing decisions. The majors, however, still had control over the oil market and while the five OPEC members produced 90% of traded oil the majors controlled 92% of their production and made unilateral pricing decisions on that production. Throughout the 1960s OPEC and the majors negotiated royalties and price determination on several occasions yet the majors remained in control. During that time OPEC grew, attracting Quatar (1961), Libya and Indonesia (1962), and Algeria (1969).

The Declaratory Statement of Petroleum Policy of Member Countries (OPEC 1968) marked the first major step towards the 1970s power shift as OPEC announced its intention to achieve control of both prices and the ownership of production. Following the declaration the Libyan government under Qadaffi began a series of confrontations with oil companies producing Libyan oil. In 1970 taxes were raised for independents producing oil in Libya. After initial victories against the independents Qadaffi turned to the majors who, fearful of the possible nationalisation of their interests conceded to his demands. The Libyan actions encouraged similar policies from other Middle East producers, the result being the well documented rise in power of OPEC. Control of oil supplies had by now changed hands, leaving the majors to concede to the producer nations' wishes, and to concentrate on the downstream activities over which they still exercised control. The end of the majors' control over the international oil market was finally, and dramatically signalled in 1973 with the first oil price shock.

OPEC and the Market

Following the oil price hikes of the mid and late 1970s there has been a commonly held belief in OPEC's ability to determine oil prices, and so hold a captive audience of industrialised nations to ransom. This has been countered by suggestions that OPEC is not a true cartel, that its influence over prices is more mythical than real, and that the price hikes were due to market forces.

The 1973/74 rise has been blamed on OPEC production cutbacks but such restrictions, rather than being an attempt by OPEC to force higher prices, were caused by political events, namely an oil embargo initiated against America as a response to US 'war-like behaviour' towards the Arabs in the third Arab-Israeli war. The large price rises were the result of deliberate restrictions on output undertaken for political purposes rather than to achieve monopoly profits. Just as the 1973/4 price rise occurred in the time of the Arab-Israeli war, the 1979 rise occurred during the Iranian revolution. The revolution brought uncertainty over future oil supplies, leading oil companies to build up stocks, and to speculative purchases of oil which together increased prices even further before Iran reduced its output. The Iranian revolution led to oil price rises simply because it affected the current and expected future supply of oil.

From mid 1977 to the end of 1978 the real price of oil had continually fallen, although the nominal price remained constant. By the end of 1978 political disturbances in Iran caused a fall in Iranian output which led to an increase in spot prices. Following that reduction OPEC decided in December 1978 to raise the price of Saudi 'marker' crude. The OPEC increases could be described as modest (10% in four instalments over the year) but they became 'obsolete' as Iranian exports ceased altogether in 1979. Prices rose above those announced in December 1978 due to demand and supply imbalance. The price increase could, therefore, be explained as a simple market equilibrating process in response to a fall in supply. By June 1979 spot prices were $38 p/b and since the official posted price was $15, an OPEC meeting in June increased the price to a limit of $23.50 p/b.

To summarise, the discussion so far has seen that through its history the oil market has seen its price influenced, with varying degrees of success, by multinational oil firms and producer nations; the most infamous example of the latter being the quasi cartel, OPEC. Since the early 1980s however, the oil market has witnessed the decline of OPEC and the growth of spot trades where the price of oil is implicitly market-determined. As will be made clear shortly, the majors' loss of control over the oil industry was a major contributing factor in the increasing use of spot markets for trading oil. Paradoxically it was the increasing use of spot markets which ultimately circumvented any power that OPEC may have had over oil prices, so leading to OPEC's ineffectiveness.

Within the standard economic framework where prices are the result of supply and demand interaction, it is difficult to accept the OPEC posted price as the price for oil.

The OPEC posted price does not represent a market determined price, nor does it represent a price at which oil may actually be traded, but is the price which OPEC would prefer its members to offer their oil for sale. Moreover, the price acts merely as a guide to OPEC members and does not (and cannot) face active enforcement through production control. In addition it should be noted that the OPEC posted price is set for a 'marker' crude - usually Saudi light crude - around which other crudes are priced with respect to their different specifications.

The suggestion that OPEC posted prices and market prices can be very different is exemplified by OPEC moves in 1989 to lift its reference price above $18 p/b even though spot market prices had been about $4 below that level for some months. While this point illustrates the not surprising fact that OPEC posted prices do not represent traded prices for oil, it is appreciated that posted prices may influence market prices as market expectations react to OPEC announcements. Furthermore, while OPEC has attempted to interfere in market mechanisms by limiting the supply of oil through restrictions on its members' production, the success of such policies has been limited due to the widespread violation of quotas. To a large extent it has been the actions of Saudi Arabia, which has some of the world's largest oil reserves and so an incentive to keep prices low, which has undermined OPEC's output restrictions.[4] Latterly North Sea production and that of other non-OPEC countries has frustrated OPEC attempts to increase the price of oil.

[4] Given its large oil reserves Saudi Arabia has an incentive to keep oil prices relatively low in order to ensure oil's continued consumption. High oil prices would lead to lower consumption per se together with a shift to substitute energy sources.

I 1.4 THE GROWTH OF THE SPOT MARKET FOR CRUDE OIL

OPEC posted prices aside, the actual price at which crude oil can be bought and sold falls into two categories; term or contract prices, and spot prices. Term sales are represented by contracts to trade where the trading prices tend to remain stable over longer time periods so long as markets remain orderly. Term contracts are agreed upon in order to give greater security in terms of supply, and whilst spot prices may fall below term prices the purchaser may deem the premium worthwhile if it assures delivery of the commodity. Contract prices will of course change, and although they do so infrequently they will respond to the dictates of market conditions. Spot prices on the other hand can change much more frequently. Spot prices are more prone to fluctuation because they are determined independently at each point in time and so can respond better to new information and supply/demand conditions.

Until the end of the 1970's the vast majority of internationally traded oil was traded and priced by long-term contracts, with the spot markets having only a marginal influence on contracted oil prices; spot markets accounted for less than 10% of internationally traded crude. Subsequently the nature of the market for crude oil has witnessed spot markets playing a prominent role. By the early 1980's spot markets were handling more than 50% of internationally traded crude, with that figure rising to 65% by the mid-1980s. The rise of spot transactions to the position of representing the largest market for physical oil trading has important implications for futures markets.

Since 1973 the majors' share of the world trade in oil has substantially declined, and this decline has been accompanied by the greater use of spot markets for trading crude oil. Prior to 1973 the majors commanded integrated networks taking crude oil from its source through the refining process and finally to the point of sale. The link from wellhead to retail outlet was broken by the rise in power of the producer nations, leaving the oil companies to focus their attention on refining and the sale of oil products. The result was an increase in the amount of oil traded outside the integrated networks as the oil companies became active participants in the spot market.

In addition to the changing pattern of oil trading brought about by the majors' decline, it has been suggested that the most permanent effect of the Iranian revolution on the oil market was not the 1979 price rise but was its impact on the role played by spot markets. The increasing importance of spot markets outlined above can be traced back to the 1979 price increase. The 1979 oil price shock saw the oil industry respond by massively increasing production. Oil prices had risen above $30 p/b and this factor, combined with the fear of oil depletion and the threat of OPEC's actions, led to the belief that prices would continue to rise. The promise of persistently high prices prompted large-scale investment in oil production both within existing areas and in new regions.[5] The illusion of increasingly high oil prices was shattered, however, by the economic recession of the early 1980's, increased energy efficiency and switching to alternative fuels; between 1978 and 1985 oil's share of the declining market for

[5]Yergin (1991) notes that the 1979 oil price shock coincided with increasing production from Alaska, the North Sea, and Mexico. In addition, Angola, China, Egypt and Malaysia became significant exporters of crude.

energy in industrialised nations fell from 53% to 43%.[6] Demand for oil began to fall as did the real price of crude as production capacity exceeded demand, leading eventually to the oil price slump of the mid-1980's.

Much of the new oil production from non-OPEC sources began to trade on the spot markets rather than the more traditional term (forward) markets. Trading on the spot market brought oil prices which were responsive to market conditions and substantially different from OPEC's 'official' prices. Consequentially the early 1980s saw the majority of internationally traded crude exchanged on spot markets or traded at prices directly related to spot prices. The emergence of spot markets as the primary arena for trading crude oil brought with them a growing realisation of the drawbacks of trading on the spot markets; most notably the price risk faced by those with spot commodity commitments.

It was this uncertainty which led to another important event in the chronology of the international oil market; the establishment in March 1983 of futures contracts for crude oil by the New York Mercantile Exchange. The importance of both the growth of spot trading and the introduction of futures for oil was to bring crude oil finally into the realms of a competitive market. In its history the price of oil had been largely dictated by the oil majors followed by the producer nations and OPEC. By the early 1980s the price of crude was determined by the market and oil had become a traded commodity like any other.

[6] High oil prices have political as well as economic consequences, and these factors led to moves to reduce dependence on oil. The early 1980's witnessed a shift back to coal and natural gas for electricity generation, in addition to the development of new nuclear capacity.

I 1.5 THE FUTURES MARKET FOR CRUDE OIL

Futures markets are born of risky spot markets. One can say that the single, overriding reason for the existence of futures markets is the facility they offer for sharing the risk arising from price variability; without price variability there would be no risk to share, and so no need for futures markets.[7] The international oil market has been witness to a great deal of price change and price uncertainty. Its history is abundant with examples of price volatility; selected examples include, the Suez crisis 1956, the 1973/4 and 1979 price shocks, the price collapse in 1986, the Exxon Valdez and Piper Alpha disasters, and the recent the Gulf Crisis. Such uncertainty and volatility in the price of oil, together with its status as the most important commodity in the world substantiates the need for underlying futures markets.

In any market the buyers and sellers of a commodity will face uncertainty about the future price at which they will be able to transact. Such uncertainty has a real economic impact in that it can lead to reduced production and consumption and so result in potential welfare losses. As mentioned above, the oil market has traditionally responded to future price uncertainty by using long-term contract agreements for trading oil. Given the frequent and often large price swings experienced by the oil market contract sales have become outmoded. While the supersession of spot transactions allowed oil to be traded at more realistic prices, they brought with them the cost of greater uncertainty. The response to this uncertainty has been the

[7] This risk transferring function is only necessary in markets which are inherently volatile, or where the spot market alone cannot provide sufficient hedging opportunities.

introduction of futures markets for crude oil and its physical derivatives.

Prior to the launch of the NYMEX futures contract, crude oil futures were not traded (or required) since the market was dominated by term contracts which experience very little short-term price variation. The introduction of the contract established the New York Mercantile Exchange (NYMEX) as the world's major market for energy futures,[8] but has also promoted interest in energy futures from other countries. London's International Petroleum Exchange (IPE) established futures contracts for Gasoil in April 1981, for crude oil in June 1988, and for unleaded gasoline in January 1992. The Singapore International Monetary Exchange (SIMEX) launched futures contracts for crude oil in February 1989, and Gasoil in June 1991.

Until the beginning of 1992 the international market in crude oil futures centred around the three main exchanges listed above: NYMEX, which trades futures for WTI crude and sour crude; the IPE which trades futures on Brent crude; and SIMEX trading contracts for Dubai sour crude. In January 1992 the SIMEX crude oil contract was delisted, leaving New York and London as the effective market for crude oil futures[9]. An indication of the relative size of the main futures markets is given in Table 1.2 below. It is clear from this information that the US market for futures traded on crude oil and its physical derivatives is by far the most important. The IPE has a significant share of the trade in crude oil futures but is overshadowed by its

[8] The first energy futures contract launched by NYMEX was for Heating oil in 1978. In 1985 a contract for unleaded gasoline was also launched.

[9] The IPE launched a futures contract for Dubai sour crude in July 1990 but the contract was delisted in November 1992.

transatlantic peer. The volume of crude oil futures traded on the IPE does, however, continue on an upward trend; the trading volume for 1991 was 5.1 million contracts, while 1992 saw 6 million crude oil contracts traded. The size of the IPE Brent futures market is illustrated in Figure 1.1 which gives monthly volumes aggregated over all maturity groups. The low trading volume of SIMEX crude oil futures shown in Table 1.2 explains the contract's eventual demise. The magnitude of crude oil futures trading can be put into perspective by considering the trading volume of other commodities. With reference to Table 1.2, the largest traded (non-oil) commodity futures contract in the US was the Chicago Board of Trade's corn contract; 11.4 million contracts were traded in 1990. The largest non-US commodity was the Tokyo Stock Exchange's futures for raw sugar, with 6.4 million contracts trading during 1990.

Table 1.2

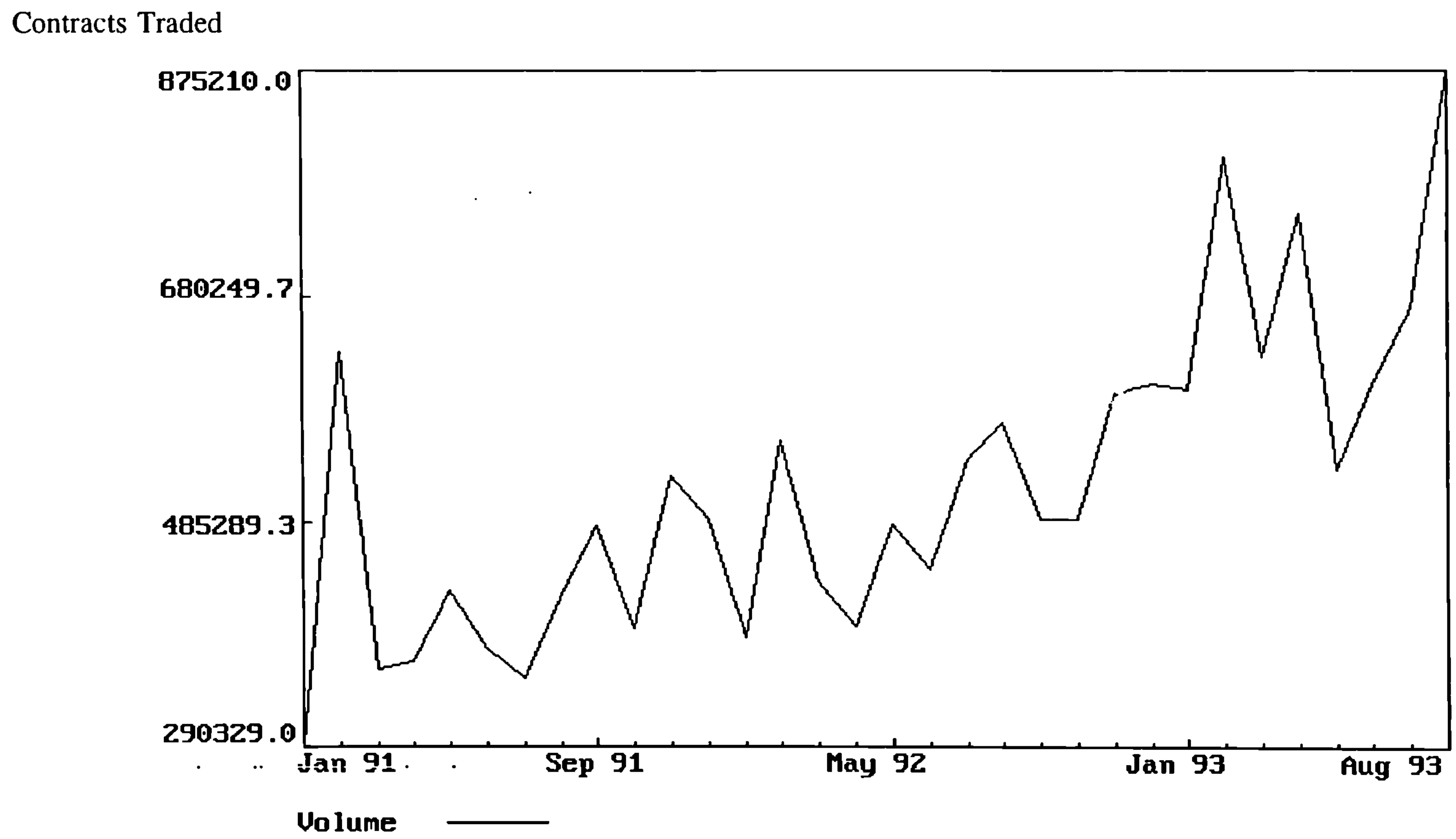
Trading Volume for Major Oil Futures Contracts: 1990

Exchange	Contract	Trading Volume
NYMEX (US)	Crude oil	23,686,897
"	Heating Oil	6,376,871
"	Unleaded Gasoline	5,205,995
IPE (UK)	Crude oil	4,083,092
"	Gas oil	2,603,095
SIMEX (Singapore)	Crude oil	213,918

Source: Edwards and Ma (1992)

Figure 1.1

IPE Brent Futures Monthly Trading Volume



II The Economics of Futures

II 1.1 Introduction

In Section I it was suggested that futures markets are born of price uncertainty. Futures markets present market agents (both hedgers and speculators) with the opportunity to adjust their risk-return profiles in a way which participation in the spot market alone cannot. In offering this facility, futures markets aid the completion of otherwise incomplete markets. It is this function of broadening the set of state contingent payoffs that represents the underlying social benefits derived from futures markets.

The advantages of trading in futures markets come from their relative ease and cheapness. As an example of the ease of using futures we may consider an agent entering a crude oil futures position where contracts are for cash settlement. In this case the agent will trade 'paper' barrels and will never come into contact with 'wet' barrels, their production, processing, transportation, storage, or delivery. The same argument applies equally for futures contracts which require physical delivery since the contract can be formally 'closed out' leaving the speculator free from a physical commitment in the commodity. The relative cheapness of using futures rests upon their particular characteristics. These characteristics are; the standardisation of the commodity and prespecified expiration date, low transaction costs, large open interest relative to the supply of the deliverable commodity, and high leverage.[10]

[10] Futures markets represent highly levered positions because the investment required to cover a future's margin is small in relation to the value of the underlying commodity which the futures position represents.

To begin we describe the nature of spot prices. As noted by Powers (1970), spot prices are not entirely anticipatory and so may be considered to be composed of two elements: a systematic component which reflects fundamental economic conditions, and a random component which captures noise and disturbances in the price system. It is desirable that the pricing system conveys accurate information so that efficient allocation can be attained. This is consistent with the systematic component of prices being responsive to changing fundamentals, and the random component tending towards zero. The question of interest here relates to the effect of the introduction of a futures market on these two elements. Powers presents a persuasive argument that the random component of prices is inversely related to the degree to which market agents are informed of fundamental conditions. From this point Powers suggests that the existence of futures trading should increase information dissemination leading to;

> "... more informed decision making and prices that are closely representative of basic supply and demand conditions; prices whose random element is less than it would be without futures trading; prices that are ... less distorted by noise."
> [1970, p. 464]

As such we can expect futures to improve efficiency in spot prices and also reduce random price movements. Evidence relating to these two points is explored within this section, where we review investigations of the effects of futures trading on spot market volatility together with their information effects in terms of providing unbiased predictions of future spot prices, and exhibiting contemporaneous price discovery or dominance. In addition we also consider information effects within futures markets by reviewing studies of the relationship between information, trading volume and price movements in futures markets.

II 1.2 Futures Trading and Spot Market Volatility

The most persistent criticism of futures markets is that they encourage speculation which destabilises prices in the underlying market for actuals. While this view is held amongst a number of market practitioners, regulators and academics alike, a consensus of opinion has not been reached. There is a substantial body of empirical as well as theoretical evidence which suggests that futures markets have no adverse effect on spot price volatility, and that they may even improve price stability. The opposing theoretical views as to the exact influence of derivative trading on spot prices have been unable to resolve the debate. This has led to increasing attention being paid to the use of empirical analysis as a way of providing answers. This section begins with an explanation of the opposing theoretical arguments of the effect of futures trading on spot market prices, and the proceeds to discuss the evidence provided by previous empirical studies.

As discussed in Section II 1.1 above, the advantages of trading in futures markets relate to their relative cheapness and ease of use. This freedom is cited as the root cause of futures markets encouraging speculation which allegedly damages spot market stability. The presumed adverse effects on spot price volatility have been a major impetus behind demands for greater regulation of futures markets. Opponents contend that it is the unique features of futures markets which foster an environment conducive to speculation. The question of regulation is very important for futures markets since the introduction of further, unnecessary restrictions on their operations could have negative effects on their functioning and effectiveness, thus curtailing the benefits they bring.

There is no objection in the literature to the view that futures markets permit, and indeed encourage speculation. Since spot and futures prices move closely together, speculators in futures markets may participate in price movements without becoming directly involved in the (relatively more expensive) underlying actual. Indeed, speculation is vital for the survival and effective operation of futures markets since it supports the hedging function. The contentious issues relate to the effect of this speculation.

It is not fully clear why an increase in volatility *per se* should be cause for concern, other than greater volatility leading to the perception of greater risk, so increasing any risk premia. Edwards (1988a) argues that care must be taken when interpreting observed increases in volatility since they need not necessarily reflect the destabilising outcome of excessive speculation; the noise component of prices. If one accepts that observed increases in volatility simply reflect information or expectations about fundamentals, then that volatility has no apparent social cost. In fact, the volatility would be an indication of improved information discovery. Indeed the results presented in Chapter 2 of this thesis would support this latter conclusion.

The influence of speculators on price stability is an issue long debated in economics, and attracted interest long before the introduction of derivative instruments. Kaldor (1939), argues that sophisticated speculators would exacerbate price changes by selling to less well informed agents at prices above that which a competitive equilibrium would dictate. Friedman (1953), responds to the claim that speculators will view a decline (increase) in prices as a signal for further fall (rise) and so trade in a fashion which makes price movements sharper than they otherwise would have been; this practice leading to price destabilisation. According to Friedman this line of reasoning requires speculators to lose money on average since their actions can only be destabilising if they sell when prices are low and buy when they are high.[11] However, while Friedman argues against the presumption that speculation will be necessarily destabilising, he accepts that destabilisation may result.

While not suggesting that speculation cannot lead to price stabilisation, Baumol (1957), disputes the universality of the proposition that speculative activity is necessarily stabilising. From a starting point where speculators realise that they do not have the ability to accurately forecast future prices, Baumol suggests that speculation will involve selling after a price peak has passed, and buying after an upturn has commenced. This leads to the observation that despite possible stabilising influences,

> "[speculation] must also have a destabilizing influence in accelerating both upward and downward movements because speculative sales occur when prices are falling, and purchases are made when prices have begun to rise." [1957, p. 263]

With direct reference to futures markets, Harris (1989) suggests that the increase in well informed speculative trade brought to the market by the onset of derivative

[11] Friedman warns that this claim is a simplified generalisation.

trading may have two opposite effects on volatility. The market may experience an increase in price volatility as futures trading enhances the price discovery mechanism and so new information concerning fundamentals is more rapidly impounded into prices.[12] Since futures markets face less friction than spot markets, particularly with respect to lower transaction costs, prices should respond more quickly to new information. Through a process of arbitrage these price adjustments will be transmitted to the underlying spot market. In a similar vein, Chassard and Halliwell (1986), comment that speculation can artificially distort price movements so as to exaggerate the normal response to fundamentals.

Volatility could, however, perceivably decrease in the presence of futures due to the liquidity which speculators provide the market. Such liquidity would allow spot traders to hedge their positions and so curb volatility attributable to order imbalances. Figlewski (1981) comments that the risk transference opportunities afforded by futures markets may also reduce spot price volatility by removing the need to incorporate a risk premium to compensate for possible adverse future price shifts. In this case it would be a lack of liquidity, due to insufficient speculative trading, which would induce volatility. This issue is explored in Chapter 2.

As previously stated the volatility question is unresolved on a theoretical level and so it is to empirical testing which we must turn in order to gain insights into this relationship. Previous investigations into the effects on spot price volatility of

[12] It is widely recognised that a major economic function of futures markets is their price discovery role. See Chapter 4.

derivative trading have been carried out for a variety of physical commodities as well as for financial instruments, with analysis being confined mainly to US markets. The empirical techniques used are varied but the general approach is to consider spot price variability in periods before and after the onset of futures trading and to test for significant changes. Less common is the use of cross-sectional analysis where spot volatility is compared for similar markets with and without futures trading. A notable point is that the vast majority of previous studies have been characterised by the use of constructed measures of volatility which can lead to results being dependent upon the definition of volatility. Recent advances in econometrics, however, have allowed volatility to be modelled directly, and a number of studies have utilised these techniques.

In general, past empirical studies have found that the establishment of futures trading has either reduced the price volatility of the underlying commodity/asset, or has had no discernable effect. Technical assessment of the influence of futures trading has ranged from simple static regression, univariate Box-Jenkins analysis and causality tests to multivariate time series analysis, Box-Tiao intervention analysis, and, more recently, ARCH models. The early empirical literature in this field is very extensive and to discuss this work in detail would be cumbersome. As such this review provides a tabulated summary of selected studies in Table 1.3. Detailed reviews are reserved for more pertinent studies, with their inclusion determined on the grounds of methodology adopted or market investigated.

Table 1.3

Summary of Studies into the Impact of Futures on Spot Price Volatility

Author(s)	Futures Contract	Effect on Spot Volatility
Hooker (1901)	Corn	Reduction
Working (1960)	Onions	Reduction
Gray (1963)	Onions	Reduction
Naik (1970)	Hessian	No discernable effect
Powers (1970)	Pork bellies, Cattle	Reduction
Tomek (1971)	Wheat	Reduction
Johnson (1973)	Onions	No discernable effect
Taylor & Leuthold (1974)	Cattle	Reduction
Cox (1976)	Onions, Pork bellies, Hogs, Potatoes, FCOJ, Cattle.	Reduction
Figlewski (1981)	GNMA certificates	Increase
Bhattacharya *et al* (1986)	GNMA certificates	No discernable effect
Edwards (1988b)	Stock indices, Interest rates	No discernable effect
Brorsen *et al* (1989)	Cattle	Increase
Baldauf & Santoni (1991)	S&P 500	No discernable effect

Cox (1976) provides an analysis of the impact of futures trading on six commodities; pork bellies, hogs, onions, potatoes, frozen concentrated orange juice (FCOJ), and cattle. The investigation uses weekly observations[13] over varying sample periods ranging from 220 to 856 observations. Testing is carried out by estimating autoregressive models for spot prices in periods with and without futures trading using standard regression analysis. Cox interprets the decline in serial correlation and error variance for the post-futures models as showing that futures trading has not had a harmful effect on prices. In fact futures are seen to increase information in the spot markets and reduce volatility there, leaving Cox to criticise the motives which have resulted in restrictions on futures markets.

In an early study of financial futures, Figlewski (1981) investigates the impact of the CBOT's listing of futures for US Government National Mortgage Association (GNMA) certificates in October 1975. Figlewski constructs a series of monthly volatilities from daily prices for the period January 1975 to January 1979 using the formula given in equation (1.1) below.

$$V_t = \left(\sum_{s=1}^{N_t} (P_s - P_{s-1})^2 / N_t \right)^{1/2} \tag{1.1}$$

where V_t is volatility for month t
P_s is the cash price on day s
N_t is the number of observations in the month

The above measure marked an improvement on the previous practice of measuring

[13] A single daily price for each week is used as the weekly price.

volatility as the difference between high and low prices in that it accounts for fluctuations in between. The study regresses the spot volatility series against four factors; volatility in a control market (10 year T-bonds), spot market liquidity, a measure of inflation, and futures market volume. Results imply that futures trading leads to increased spot volatility and suggests that this is caused by futures traders being less well informed relative to their spot market counterparts.[14] Figlewski argues, however, that the costs induced by extra volatility do not necessarily imply that the futures have no value.

> "In judging the social value of the GNMA futures market, it is important to recognise that increased cash price volatility is only one aspect of the question. Against the "costs" associated with wider price variation one must weigh the significant benefits of extending the possibility of hedging interest rate risks to a much wider audience." [1981, p. 447]

Simpson and Ireland (1982), further examine the effects of the introduction of futures trading on GNMA certificates using standard OLS regression and a multivariate model with intervention term. The study uses the first differences of both daily and average weekly prices. For daily data the sample consists of 150 observations both before and after the onset of futures trading, with the weekly data having 62 observations preceding and following futures trading. Preliminary investigation is undertaken

[14] If futures traders do not have as good information as than spot traders, futures prices will contain noise which will be transmitted to the spot market.

through the specification of a static regression model with a control variable, for which there was no futures trading, to remove extraneous influences, and a dummy for the onset of futures trading. The regression model was constructed for both pre-futures and post-futures sub-samples and run for daily and weekly volatility measures. The use of Chow tests for significant changes in the model's parameters between the two periods suggested no significant change, leading the authors concluded that there had been no increase in spot price volatility since the advent of derivative trading. These conclusions were confirmed by the results from the multivariate model with intervention term.

Bhattacharya, Ramjee and Ramjee (1986), use the constructed measure of volatility furnished by Figlewski (1981) to calculate weekly volatility series for spot and futures prices for GNMAs. The authors base their empirical investigation on the hypothesis that if futures market volatility causes spot market volatility, then the former's influence on the latter can be assessed with causality tests. To this end the study adopts the Granger causality methodology to test weather futures market volatility has caused spot market volatility. Results generally show futures volatility to have some causal influence on spot market volatility, but the relationship is weak. The authors argue in this case that since evidence of causality is not pervasive the results provide indirect evidence to suggest no change in spot volatility since futures trading began. The use of causality tests to investigate the impact of futures trading has since been criticised. Edwards (1988b), suggests that causality tests cannot be used to infer the effects of futures trading on spot market stability, arguing that the appearance of futures volatility leading spot volatility could be explained by futures markets reacting more quickly to information which will eventually reach the spot market where it will have a like effect on volatility.

Brorsen, Oellermann and Farris (1989), study the effect on spot prices due to the introduction of a live cattle futures contract. The investigation uses daily average prices for eight years before and eighteen years after the listing of futures contracts. The methodology adopted involves the regression of the standard deviation of spot prices on a constant plus control variables and three of dummy variables; the latter relating to three distinct stages during the period of futures trading. A positive sign on a dummy variable's coefficient indicates that the dependent variable (spot price standard deviation) increased relative to the pre-futures period. All dummy variables were found to have positive coefficients. While the study also presents evidence that spot market efficiency improved in the presence of futures trading, it shows that short-term price risk increased, thus adding credence to the commonly held belief amongst cattle producers that the futures market was destabilising. The authors pose questions similar to those raised by Figlewski (1981), namely whether the increase in short-term volatility outweighs the benefits brought by lower long-term volatility, improved efficiency and hedging opportunities. The authors decide in favour of futures markets.

Edwards (1988b), considers two groups of financial futures, stock indices (S&P 500 and Value Line Index) and short-term debt instruments (90-day US T-bills and 90-day Eurodollars). The analysis uses both daily and intra-day data to construct a number of volatility measures with the aim of testing the sensitivity of results to volatility measure used. The investigation proceeds by calculating volatility for with-futures and without-futures periods and employing F-tests to detect significant increases in the measures' values. While some mixed evidence is found, the main conclusion of Edward's study is that the presence of the various financial futures considered have not had a destabilising influence on their respective spot markets.

More recently, Baldauf and Santoni (1991) have employed ARCH techniques to test for possible effects on volatility in the S&P 500 due to the inception of futures trading and the growth of program trading. ARCH models offer a much more attractive technique for testing volatility due to their property of modelling volatility directly, so escaping the problems associated with the choice and use of constructed volatility measures. The authors note that price returns are frequently characterised by distinct periods of high or low volatility: large price changes tending to be followed by large changes, and small price changes being followed by small changes.[15] This observation suggests that volatility is heteroskedastic in nature, and so requires that this is taken into account if reliable inferences are to be made. Baldauf and Santoni specify ARCH models for the spot price (returns) series before and after the onset of futures trading and test for significant change in their parameters. The study finds no evidence of a shift in the model parameters suggesting no effect on volatility from derivative trading.

Summary

From the preceding reviews it is evident that while a history of research has been

[15] This observation is attributed to Mandelbrot (1963).

undertaken into the question of volatility transference, the research has used a diverse set of methodologies and volatility measures, with the consequence that there is a lack of consensus. The use of constructed measures of volatility is subjective and can lead to results being dependent upon the particular measure chosen. More recent investigations in this field have adopted a more objective measure of volatility in the form of the conditional variance as specified by an autoregressive conditional heteroskedasticity (ARCH) model as provided by Engle (1982). In Chapter 2 of this thesis volatility transference is investigated using GARCH models. Furthermore, while previous studies have addressed the volatility question in terms of changes in the absolute level of volatility, a greater insight can be gained into the effects of futures trading on spot prices by considering changes in the nature of volatility. The use of GARCH models also permits this form of analysis. In addition, Chapter 2 also investigates the contribution of noise to volatility changes.

II 1.3 The Efficiency of Futures Markets

Futures markets are often described as having two important social functions; facilitating the transfer of price risk, and providing forecasts of future spot prices. With respect to these functions French (1986) asserts that,

> "The evidence that futures markets transfer price risk is irrefutable. However, there is some debate about the markets' forecasting ability." [1986, p. S38]

It is evident that the forecasting ability of futures prices is an issue which commands much attention. This faculty is commonly referred to as the futures price being 'efficient,' in that it will reflect all relevant and available information germane to the prospective future spot price. Testing this role is typically undertaken by assessing the futures' ability to unbiasedly predict the future spot price of the actuals upon which they are written. For futures prices to satisfy this ascribed function two conditions must hold. First, market agents must exhibit risk neutrality. This condition must be interpreted with care, since it does not impose risk neutrality on individual agents, but implies that the aggregate market will exhibit risk neutrality. The second condition is that all relevant, available information is rapidly and accurately impounded into futures prices. These conditions form the joint hypothesis of efficient futures prices, a detailed explanation of which is reserved for Chapter 3. Failure to satisfy the first condition signifies the presence of a risk premium, in which case the futures price would be biased by an amount equivalent to the risk premium. Such bias could be constant or time-varying depending upon the nature of the risk premium. Failure to satisfy the second condition suggests that even under risk neutrality futures prices will give biased forecasts of expected future spot prices.

Tests of futures markets' efficiency with respect to the joint hypothesis outlined above have typically been undertaken using one of two general methods; standard regression analysis and, more recently, cointegration techniques. Prior to the development of cointegration techniques the ability of futures and forward contracts to unbiasedly predict future spot prices was investigated using OLS regression analysis. Such studies commonly specified the spot-futures relationship by regressing the natural logarithm of the spot price realised when the futures contract expired, (S_{t+n}), on the natural logarithm of the current price of that futures contract, ($F_{t,t+n}$);

$$S_{t+n} = \alpha + \beta F_{t,t+n} + \epsilon_t \tag{1.2}$$

Within this framework efficiency is implied when the coefficients of the regression equation obey the restrictions $\alpha=0$ and $\beta=1$ according to an F-test. These restriction are interpreted as implying risk neutrality and the rational, efficient use of information respectively. The main drawback with the above analysis is that financial time series data are commonly nonstationary in levels, thus leading to unreliable inferences based on OLS regressions. A major advance in testing efficiency has been provided by the development of cointegration procedures, see Engle and Granger (1987). Cointegration is given detailed treatment in Chapter 3, and is accordingly given only cursory treatment at this juncture. Engle and Granger cointegration specifies a cointegrating regression between two variables as in equation (1.2) above. In the case where the variables are nonstationary in levels, but where the residuals from the cointegrating regression are stationary, the variables are said cointegrate. Cointegration implies a long-run equilibrium between the variables which indicates, but does not guarantee efficiency.

The second main methodological issue in testing efficiency commanding attention centres around the testing of the restrictions on the parameters in equation (1.2). As shown by Elam and Dixon (1988), the F-test of a=0 and b=1 is inappropriate when dealing with nonstationary variables since it is prone to Type I errors. Solutions to this problem have been provided by the Johansen cointegration procedure, Johansen (1988), which is explained in Chapter 3.

Since standard regression analysis has given way to cointegration in tests of the unbiasedness hypothesis, the following review of the literature will not be detained by examples of the former methodology. Focusing on cointegration tests for efficiency, one sees that a large proportion of investigations have involved forward markets as opposed to futures markets. This point does not affect their relevance to a study of futures markets, however, since the underlying principle is the same.

Hakkio and Rush (1989) test efficiency in the foreign exchange market for sterling-Deutschemark forward contracts for the period 1975 to 1986 utilising Engle and Granger cointegration. The study examines cointegration between the spot and forward exchange rates within the UK and Germany. In testing efficiency the authors set three hurdles: that the spot and forward series cointegrate, that the cointegrating vector assumes a value of unity, and that the parameters of the error-correction model may be restricted such that it reduces to the equilibrium relationship, $S_{t+n} = F_{t,t+n}$ (see section 3.4). The study's results imply cointegration between the spot and forward rates but the use of Engle and Granger cointegration prevents the verification of the second condition for efficiency, that the value of the cointegrating vector is unity. The authors do, however, report a value close to one based on casual observation of the regression results. Inspection of the error-correction models for sterling and the Deutschemark, however, lead the authors to reject the joint hypothesis of risk neutrality and the rational use of information for both the British and German exchange rates. In both cases the parameter restrictions on the ECM required for efficiency could not be validated. The authors conclude by noting that while results from tests for cointegration were consistent with, and indeed implied efficiency, the use of error-correction models allowed the rejection of the joint hypothesis. The precise nature of the rejection cannot, however, be identified.

Serletis and Banak (1990) apply efficiency tests to NYMEX petroleum futures contracts for heating oil, unleaded gasoline, and crude oil. The authors consider spot and one month futures contracts over a sample period from 1983 to 1988 (1985-1988 in the case of gasoline). The study favours the Phillips-Perron tests for unit roots, (Phillips and Perron 1988) as a robust alternative to the original Dickey-Fuller tests, (Dickey and Fuller 1979). The Engle and Granger cointegration procedure is adopted but the residuals from the cointegrating regressions are subjected to Phillips Perron tests. The authors establish spot-futures cointegration for all three markets studied and report the intercept and coefficient on futures prices from the cointegrating regression to be "generally very close" to 0 and 1 respectively. From the empirical results the conclusion is drawn that there is strong evidence for efficiency between spot and one-month futures prices for the NYMEX petroleum futures contracts.

Serletis and Scowcroft (1991) use cointegration to test the efficiency of Chicago Board of Trade futures for six agricultural commodities: wheat, corn, oats, soybean, soybean oil, and soybean meal. The study takes as its sample the period 1985 to 1990 for all commodities, using the expiring futures price as a proxy for the spot price. The study differs from most previous investigations in that the data set consists of daily futures prices matched against a 'blocked' spot price, i.e. a single spot price for each month towards which all corresponding futures prices are expected to converge. As in Serletis and Banak (1990) the study uses Phillips-Perron unit root tests in preference to the Augmented Dickey-Fuller (ADF) tests of previous investigations, and adopts Engle and Granger cointegration. In addition to the use of daily data, Serletis and Scowcroft test specifically for the presence of a time-varying risk premium conditional on the hypothesis of rational expectations, using a methodology developed by Fama (1984). Results accept that all variables are stationarity in first differences, and suggest that the spot and futures series for each commodity cointegrate. Tests for risk aversion suggest the presence of a time-varying risk premium, and so implies rejection of the joint hypothesis.

Lai and Lai (1991) study efficiency for spot and forward exchange rates for five currencies against the US dollar: sterling, Deutschemark, Swiss franc, Canadian dollar, and Japanese yen. The sample used consists of monthly observations from 1973 to 1889. The study acknowledges the appeal of Engle and Granger cointegration for testing efficiency between nonstationary variables, but recognise its limitations in that it fails to allow clear statistical inference with respect to the parameter values of the cointegrating regression. This is an important drawback given that proper tests of efficiency rely upon the parameters being adequately tested. If one fails to establish that the restrictions are upheld then $F_{t,t+n}$ cannot be deemed to provide an unbiased prediction of S_{t+n} even when the two series have a long-run concurrent evolution. In response to this drawback the authors recommend the use of the Johansen statistical procedure for tests of efficiency since it permits formal testing of the equilibrium relationship's parameters.

Test results indicate cointegration between spot and forward prices for all five exchange rates. Conversely, the parameter restrictions required for efficiency are rejected in all cases, leading the authors to conclude that forward exchange rates appear to be biased predictors of the future spot rate. As with previous studies the authors note that the precise reason for rejection of the joint hypothesis cannot be identified given current statistical procedures.

Barnhart and Szakmary (1991) test for efficiency for spot and forward exchange rates using Engle and Granger cointegration. The study covers a sample period from 1974 to 1988, and considers monthly observations of the US dollar exchange rate with sterling, the Deutschemark, Canadian dollar, and the yen. Preliminary analysis confirms that both the spot and forward rates for the UK, Germany, Canada, and

Japan possess unit roots and that they cointegrate. The study notes that for each cointegrating regression the cointegrating parameter is approximately one, but points to the fact that this equality cannot be reliably tested. This the authors consider to be the main drawback of previous studies of the unbiasedness hypothesis, and one they use to explain the conflicting results found in the literature. In fact the authors comment that on the basis of this parameter being close to unity, the unbiasedness hypothesis is seldom likely to be rejected. The rationale behind this statement is that,

> "... in the long run, the forward rate *is* an unbiased predictor of the realized spot, but, in the short run, there can be substantial departures from this long run relationship"
> [1991, p.252]

The failure by previous studies to recognise short-run dynamics is seen by the authors as leading erroneously to the acceptance that the long-run relationship is the true one and that efficiency holds. In response to this problem Barnhart and Szakmary use the alternative error-correction specification for the spot-forward relationship in order to test the relationship properly. The study's results reject the unbiasedness hypothesis for each exchange rate on the basis of their error-correction representations.

Copeland (1993) adopts Johansen's cointegration procedure to test efficiency in exchange rate forward contracts from 1976 to 1990 for daily and monthly observations of bilateral dollar exchange rates with sterling, Deutschemark, yen, Swiss franc, and french franc. Phillips-Perron tests for unit roots confirm nonstationarity in the levels data for each rate. The study tests for cointegration and parameter restrictions over the whole period, on a monthly basis, and a daily basis for each rate. Results are mixed for all three levels of data fineness, and Copeland concludes that while no clear pattern is revealed, the evidence suggests that the forward contracts do not provide unbiased forecasts of future spot rates.

Summary

The above review of the empirical literature highlights a number of important issues regarding tests of the unbiasedness hypothesis. First, it is essential that the stationarity of the variables be tested, and if they are nonstationary then their order of integration should be identified. Second, for nonstationary variables, cointegration has been widely adopted as the appropriate technique for testing their long-run equilibrium relationship. Although cointegration suggests efficiency it provides only a necessary condition, and as such it is desirable that the sufficient conditions for efficiency are aslo investigated. The issue of testing such sufficient conditions is taken up in Chapter 3 of this thesis.

One final point is worthy of consideration. Most studies of efficiency make two implicit assumptions. The first is that the current spot price can be improved upon as a predictor of the future spot price, and that the futures price provides this function. The intuition behind this belief arises from the much lower costs involved in participating in the futures market and their associated trading volume. Such attributes should lead to enhanced information discovery in futures markets. French (1986) suggests, however, that tests which reject futures markets' ability to forecast spot prices do not necessarily imply their inefficiency. In cases where the current spot price is equal to the true expectation of the future spot price, there is nothing for the futures market to predict.

The second implicit assumption is that the unexpected component of the realised spot price, ε_t in equation (1.2), is small; in fact the mean expected value of ε_t given the information set is zero. Since ε_t is dictated by the current available information set, participants must believe that any information not contained in that set will have a relatively small impact on the future spot price when it is eventually revealed. As noted by French (1986), the futures price may offer a good forecast of the future realised spot price, but the unexpected component of the spot price may be large enough to obscure that forecast. While the above points raise interesting questions and should be borne in mind when considering tests of futures markets' efficiency, they fall beyond the boundaries of this study.

II 1.4 Price Dominance in Futures Contracts

As stated above one of the main functions of futures markets is to provide price discovery. This function may be defined as the ability of futures to provide information on both future and current spot prices. The previous section dealt with what may be termed inter-temporal price discovery i.e. futures prices providing information about likely future spot prices. This section deals with price discovery in terms of futures having a price leadership role; discovering information more rapidly than the contemporaneous spot price. This latter function is described as price dominance and describes the degree of price discovery originating in futures markets relative to that originating in spot markets. This function has a number of important implications for hedgers, speculators, arbitrageurs, and other interested parties since it provides insights into the nature of pricing mechanisms in those markets. Moreover, since evidence suggests that dominance patters differ across time investigations of price dominance may provide explanations of the evolution of pricing mechanisms; their sensitivity to different types of information, the effect of market maturity and changing market structure, and the impact of regulatory changes.

Price dominance relationships between spot and futures markets rest essentially upon the degree to which those markets are integrated, and studies into these relationships are intended to reveal the degree of association between the markets. As a derivative instrument the price of a futures and the price of the actual upon which it is written represent prices for what is essentially the same asset, and so are substitutable to some degree. As such spot and futures prices are expected to react in much the same way to information events. The degree of association between price responses can be measured by assessing whether one market responds to information more quickly than the other. By analysing such responses to information one can ascertain the degree of market integration. In the case of a spot and futures market being perfectly integrated one would expect to observe simultaneous reactions to news events. Where a state of less than perfect integration occurs one market will react to information earlier than the like response by its partner. In this case it is the frequency with which one market leads the other relative to it being led which indicates the type of dominance relationship between the markets. Naturally, where there are no common responses to information the markets will not be integrated, and so must either represent different assets or be subject to such stringent restrictions that they cannot be considered substitutes.

In practice futures markets are commonly expected to update prices more frequently than spot markets, and hence exhibit dominance. The relative discreteness of spot prices is explained by the greater costs involved in trading on the spot market. The oil market is not expected to differ from other markets in this respect, and the lower costs associated with oil futures markets enable them to attract a body of 'paper barrel' traders not witnessed on the 'wet barrel' spot market. While dominance by futures can be attributed largely to cost differentials, a further explanation is provided by nonsynchronous trading activity. Given the nature of the oil spot market, and associated restrictions on data availability, a detailed investigation of trading patterns is not viable.

The role of futures markets as a medium for contemporaneous price discovery (or price dominance) has received much attention over the last few years, particularly with reference to stock index futures. The vast majority of studies in this field have used one or both of two main methodologies; Granger causality tests to identify significant leads and lags in responses to information, and the model for determining a ratio of dominance based on arbitrage furnished by Garbade and Silber (1983). These methodologies are explained in Section 4.2 but a brief, intuitive description of them is of use to the following review of the literature in this area. Granger causality tests, as adopted by studies of price dominance simply look for lead/lag relationships between spot and future markets to (unidentified) information events. Where market X is found to lead market Y, in a temporal rather than a causal sense, then X is deemed to exhibit dominance over Y. The Garbade and Silber measure of dominance is based on a model of arbitrage between spot and futures markets and provides a ratio of the level of dominance between markets. In this way the Garbade and Silber model indicates not only the direction but also the strength of a dominance relationship. Briefly, if the calculated ratio assumes a value between zero and 0.5 the spot market is said to dominate the futures market. For ratios between 0.5 and one, futures markets dominate. The size of the ratio thus indicates relative dominance. Since this investigation has as its primary concerns the time-varying nature of dominance, and its reaction to distinct information events, the following review is restricted to those studies which have explicitly or implicitly addressed these issues.

Oellermann, Brorsen and Farris (1989) investigate dominance for feeder cattle in the US. The study considers daily price data over the period 1979 to 1986 divided into two 4 year sub-periods to account for structural changes which took place in the market. Using the model for price dominance furnished by Garbade and Silber (1983) (hereafter, GS), the authors find the futures market to exhibit strong dominance over the spot market in the first sub-period (GS ratio = 1), and weak dominance in the second sub-period (GS ratio = .76). While the primary motivation of the investigation is the use of the GS model to assess dominance, the authors also employ Granger causality tests in order to provide support to their findings. Test results from the Granger model are consistent with the futures market dominating the spot market. By using two sub-periods Oellermann *et al* are able to highlight the fact that dominance relations can change over time, in this case due to significant structural change.[16]

Koontz, Garcia and Hudson (1990) use Granger causality, and a strength of causality measure due to Geweke (1982), to examine the extent to which dominance patterns have changed in US live cattle markets. Using weekly data the study divides the sample into three 4 year periods to examine the dynamic nature of dominance. Results show dominance patterns to be dynamic, with the contemporaneous price discovery process evolving over time to reflect structural change in the live cattle industry. The study notes that as relationships between spot and futures markets have changed so too have their dominance relationships, namely that as spot markets became more important for transactions they became less reliant on futures markets for price discovery. Furthermore, this dominance appears to be transitory, in the short-term at least, since the authors report that the futures market remains a viable medium for price discovery when the spot market is inactive. In concluding their research, the

[16] The authors do not elaborate upon the precise nature of the structural change.

authors suggest that future analysis should probe the issue of whether the nature of information affects dominance relationships. This issue has been since been given consideration by a number of authors, see below.

Schwarz and Laatsch (1991) examine price dominance in the US stock index market, namely the Major Market Index of 20 actively traded stocks on the NYSE. The methodological approach used by the authors is to apply the GS model to both weekly and daily data on the Index and its futures contract. Results based on both data frequencies suggest that spot markets dominated during the early period of futures trading as would be expected for an immature futures market. In later periods, however, the authors report futures markets becoming increasingly dominant (particularly when measured on a daily basis) as their trading volume grows at a rate much greater rate than that in the corresponding spot market. These results highlight both the temporal nature of dominance, suggesting that neither market maintains dominance at all times, while linking the varying dominance to the size of the futures market. Furthermore, the authors find that dominance depends upon type of information being revealed. Certain information will, by its very nature, be discovered first in (say) the spot market and in these instances the spot market will dominate. This too is an important finding and has implications for the effectiveness of futures as a price discoverer.

Schroeder and Goodwin (1991) examine price dominance over a fifteen year period from 1975 to 1989 for the US live hog market. The study uses daily data to calculate dominance on a year by year basis. The authors present two interesting results; first the GS dominance ratio was found to vary from year to year, although no general trend in dominance patterns was detected. Second, while the futures markets are found to exhibit (variable) dominance in general, for five of the fifteen years investigated spot markets were dominant, again with no apparent trend. These results are important in that they offer clear evidence of a changing level of dominance between markets which is occasionally extended to the point where dominance is reversed. The authors suggest that such changes can be explained by extreme price variability in the market. Thus, the nature of price movements is deemed to have an impact upon dominance relationships. Schroeder and Goodwin further employ cointegration, but this is used to investigate the separate, though related issue of efficiency.

Chan (1992) utilises intraday data to study the Major Market Index and S&P 500 over two separate sample periods using Sims lead-lag regressions. The study is the first of its kind to actually examine the effect on dominance relationships of different market conditions; the different effects due to the arrival of good news and bad news, the influence of different trading intensities (liquidity), and the impact of market-wide price movements as opposed to those of individual shares. In this respect the study attempts to test whether the type of information flowing to the market can have an influence on the routes through which it is embodied in prices. Results suggest a market characterised by weak dominance by futures markets and no effect due to the nature of news (i.e. good or bad). Trading intensities provided "no compelling evidence to suggest that lead-lag relations are affected," but responses to market-wide movements favour futures dominance. These findings further support the view that dominance varies both across markets and through time.

Quan (1992) uses monthly crude oil prices from January 1984 to July 1989 (66 observations), in what is termed a 'two-step procedure' for price discovery. The two steps involve firstly establishing a long-run relationship between spot and futures price series using cointegration, and secondly testing lead-lag relationships with Granger causality tests. In addition, Quan uses the GS model and analyses the ECM in order to provide support for his earlier findings. The study examines the contemporaneous pricing relationship between spot prices and four maturity groups for crude; one, 3, 6 and 9 months from maturity. The investigation establishes a long-run (cointegrating) relationship for spot prices and one and 3-month futures price series only. These two pairings thus proceed to be tested for Granger causality where spot prices are found to lead futures prices. The findings are confirmed with the application of the GS model with coefficients of dominance of 0.006 and 0.00 for the one and 3-month series respectively. Quan completes his investigation by returning to the long-run relationships discovered and specifying their ECMs; the aim being to study the relationships' dynamics. Examination of the ECMs again confirm dominance by the spot market.

Summary

The literature to date has centred around two leading methodologies for inferring price dominance between spot and futures markets. While both models can claim some success they do in fact model dominance from different perspectives; Granger causality models consider responses to past price changes in the related market, while the Garbade and Silber methodology has as its main focus the arbitrage links between the markets. In Chapter 4 of this thesis a model is developed which synthesises these two approaches so as to more fully explore the relations between information reception by the two markets. A second notable feature of the extant literature is the recognition of, and attempt to capture time variation in dominance relations. As seen above this has been investigated on a rather elementary level by dividing data series into sub-samples and comparing point estimates of dominance across those samples. A more appropriate approach, and the one considered in Chapter 4, is to model dominance within a time-varying framework. Since dominance relations are likely to be influenced by the rate and type of information received by markets, it would be sensible to model dominance as a temporally variable measure of market association.

II 1.5 VOLUME AND VOLATILITY IN FUTURES PRICES

"... more can be learned about the market - and, in particular, about volatility - by studying prices in conjunction with volume, instead of prices alone." [Gallant *et al* (1992), p202]

The role of volume in markets has been the subject of much empirical research, which has documented a strong positive relation between volume and price movements. Research has been based upon two theoretical explanations for a volume-price-variability relation: the sequential information model (SIM) due to Copeland (1976); and the mixture of distributions hypothesis (MDH) as proposed *inter alia* by Clark (1973). An explanation as to why a relationship exists between price variability and volume has only recently received attention in the form of a model of the information content of volume furnished by Blume, Easley and O'Hara (1994). The aim of this section is to provide a review of the body of empirical research into the volume-price-variability relation; the theoretical models are discussed in Chapter 5.

The motivation for studying the relationship between volume and volatility in futures markets comes from a number of areas. First, investigations of this type can provide insights into the structure of futures markets, notably the way in which agents receive and respond to information; the process of information dissemination, and the extent to which market prices convey information. A better understanding of this area is important to the parties involved in futures markets. A second motivation is provided by the possibility that where price changes and volume are found to be jointly determined, the use of price-volume data may improve tests of the impact of information on futures markets. Alternatively, it may indicate the efficiency of pricing in futures if past volume can be used in technical analysis to predict future price changes. This latter point has recently been analysed by Gallant et al (1992) who propose that past volume statistics could be utilised as the basis of a technical trading strategy.

Finally, the volatility-volume relationship has important implications for the design of new futures contracts and predictions of their viability. As explained by Cornell (1981), if volume and price variability are found to be related then new contracts should first be established for commodities with volatile prices since these are the contracts most likely to succeed. Logically, since futures contracts require liquidity in order to function properly, a positive volatility-volume relationship is a necessary condition for their survival. In fact, Working (1960) suggests that a common explanation for failed futures contracts is a lack of liquidity.

While the volume-price-variability relationship has been examined for both spot and futures markets, the majority of studies focus on spot financial assets, with a growing body of literature for futures. This investigation is concerned only with futures markets but an analysis of some selected spot market studies is useful in that it can contribute to our understanding of the relationship for futures. The remainder of this section is given to providing a review of the most important studies in this field. As will be seen a major drawback in most previous studies has been the failure to properly account for the contemporaneous relations between volume and volatility where found.

Table 1.4

Summary of Studies into the Relationship between Volume and Price-variability

Author(s)	Subject	Temporal Relationship
Clark (1973)	Cotton Futures	Simultaneous
Epps & Epps (1976)	Stocks (spot)	Simultaneous
Cornell (1981)	Commodity Futures	Simultaneous
Tauschen & Pitts (1983)	T-bill Futures	Simultaneous
Grammatikos & Saunders (1986)	Currency Futures	Simultaneous
Garcia *et al* (1986)	Agricultural Futures	Simultaneous
Lamoureux & Lastrapes (1990)	Stocks (spot)	Simultaneous
Najand & Yung (1991)	T-bond Futures	Sequential
McCarthy & Najand (1993)	Currency Futures	Sequential

All of the above studies find a positive correlation between price variability and volume traded. The column labelled 'Temporal Relationship' indicates whether a lead/lag or sequential relationship is supported by the investigation, or whether a simultaneous (MDH) relationship is found.

Cornell (1981) uses data from 17 futures contracts for agricultural commodities (11 contracts), metals (5 contracts), and T-bills (1 contract) to test for relations between volume and price variability. The empirical methodology adopted is a lead-lag regression of changes in trading volume on changes in the standard deviation of futures prices; the model used considers two leads, two lags and the contemporaneous value for volume regressed on the price change variable. The study's findings are that in the majority of cases the contemporaneous volume figure is statistically significant and positive in the price change equation indicating that volume and volatility are positively related. The leading and lagging variables conversely, are almost universally rejected, further suggesting the conclusion of a contemporaneous relation between changes in volume and price variability.

While the results of the study are intuitively pleasing in that they support the expected positive relation between volume and price variability, and suggest market efficiency in the sense that lagged data cannot be used for the purposes of making predictions, the suitability of the empirical techniques used is open to question since standard regression analysis cannot be used with contemporaneous regressors.

Grammatikos and Saunders (1986) use correlation and causality tests to investigate the relationship between price variability and trading volume for five different currency futures. The study measures price volatility using the Garman-Klass estimator (Garman and Klass (1980)) together with the change in daily closing prices. Volume is measured as daily trading volume, but the authors also consider daily open interest as an alternative measure of trading activity. Furthermore, maturity is tested as a surrogate for the directing variable[17], but while this variable is found to affect trading volume, it does not offer an adequate explanation of volatility.

The study cites as its main contributions the adoption of a refined measure of volatility (the Garman-Klass estimator), and the use of disaggregated price and volume data. The use of disaggregated data stems from the practice adopted by earlier studies (Clark (1973), Cornell (1981), and Tauschen and Pitts (1983)) of aggregating price and volume data across futures contracts of differing maturities. Disaggregated data offers clear benefits in isolating the relationship between volume and price-variability. In terms of the measure of volatility used, while the Garman-Klass estimator does have attractive properties (namely, that it considers price movements within days as well as across days) it is nonetheless a constructed measure of volatility and so encounters the problems previously discussed.

Consistent with the MDH the study reveals a strong contemporaneous relationship between price-variability and volume in the majority of cases, but also finds evidence of sequential relationships in a significant number (22%) of cases. In those cases where a sequential relationship was detected no common direction of causality could be deduced, suggesting bidirectional causality.

Lamoureux and Lastrapes (1990) investigate the notion that daily price volatility is related to the flow of information, as suggested by a mixture of distributions, for

[17] This stems from the proposition that news may have different values at different times along the contract's maturity, and reflects the often held belief that futures prices become more information responsive (volatile) as maturity nears, see Samuelson (1976).

twenty actively traded stocks. The primary motivation of the investigation is to study the notion that ARCH effects in daily stock returns are due to time dependence in the process generating information flows. Given the tendency for speculative price (returns) series to follow ARCH processes, the authors suggest that such characterisations can be explained by a mixture of distributions, with the rate of information flow acting as the directing variable. The empirical testing focuses upon the variance of daily returns conditional upon the directing variable. Since the daily rate of information flow onto the market cannot be observed it is proxied by contemporaneous daily trading volume. The introduction of contemporaneous volume into the conditional variance equation is found to make the ARCH effects disappear for 16 of the twenty stocks considered. Thus, the authors posit that since the ARCH component explains price variability, and volume data removes the ARCH effect, then volume can be used to explain price volatility. This observation invites the inference that contemporaneous trading volume 'causes' price volatility. Using volume as the mixing variable is consistent with sequential information models.

A major concern with the investigation, and one recognised by the authors, is that the use of contemporaneous volume to explain volatility raises the issue of simultaneity bias, in that volume will not be a exogenous variable. The study makes some attempt to circumvent this problem by using lagged volume in the ARCH specification, but this variable is found to have little explanatory power. As a consequence the authors present their results as valid with the proviso that they may be subject to an unquantified specification bias.

Najand and Yung (1991) examine volume-volatility relationships for US Treasury-bond futures with a GARCH model. In common with Lamoureux and Lastrapes (1990), the study considers causality in only one direction, testing for the ability of volume to explain price variability. A six year period is used to model the volume-volatility relationship both for each year individually and for the full sample. Using contemporaneous values for volume in the GARCH equation generates results which suggest statistically significant correlation between volume and volatility in only two of the six years; the full sample also fails to find correlation. This finding is attributed by the authors to simultaneity problems caused by volume being endogenous to the system explaining volatility. In response to this problem the authors use lagged volume data in the GARCH equation as a way of 'exogenising' volume. With this adjustment made the correlation becomes significant for the full sample and five of the six sub-periods.[18] The study concludes that volume is endogenous to price volatility and that volume and volatility are positively correlated. Implicit in this conclusion, though not stated directly by the authors, is the observation that the volume-volatility relationship is not contemporaneous but sequential. Unlike the study by Lamoureux and Lastrapes (1990), however, the authors find that ARCH effects remain when current volume is included in the equation for the conditional variance.

Garcia, Leuthold and Zapata (1986) investigate five agricultural commodities; corn, wheat, soybeans, soybean oil and soybean meal traded on CBOT for volume-price-variability relationships using Granger causality. Four measures of price-variability are

[18] This contrasts with the study by Lamoureux and Lastrapes (1990) which finds lagged volume to be insignificant.

used; daily price change, daily returns, daily price range and an adjusted daily price range. In addition two measures for volume are utilised; daily trading volume and volume relative to open interest, the latter measure aimed at controlling for variations in trading volume between commodities and over the life of a contract. The period examined is from 1979 to 1983 with contracts selected at intervals of five to seven months in order to avoid problems of overlapping data, yielding eight contracts per commodity. Each contract is sampled for a period of one year divided into three four-month sub-periods. Results suggest the existence of some leads and lags between price-variability and volume; 15% of cases detected such a result with the leads/lags split almost equally between the two variables. These findings were insensitive to the measure of price-variability and volume used. Where simultaneous relationships were established, however, the measure of price-variability does have a strong effect on the degree of simultaneity. This latter observation has obvious implications for the reliability of results (a point highlighted by the authors), and provides a valuable comment upon the conclusions from studies using constructed measures of price-variability. Overall the study concludes that there is no discernable lead-lag pattern in volume-price-variability relationships; the majority of cases suggesting a contemporaneous relation.

McCarthy and Najand (1993) use state space modelling to identify the causal link between daily currency futures trading volume and price returns for five currencies against the US dollar. Causal relations are tested for both price returns *per se* and absolute returns. Evidence from price returns is consistent with a number of previous studies in that no relation is found between the direction of price movements and trading volume. This finding lends support to Karpoff's (1985) assertion that price change *per se* and trading volume should not be related for futures contracts. The study finds a positive causal relationship from volume to absolute price change for four of the currency futures, that is lagged volume can explain current price returns. Moreover, for three of the four returns series explained by lagged volume, the coefficient on volume is negative implying that an increase in volume has a stabilising effect on returns. Turning to the effect of price-variability on volume, all currencies exhibit lagged returns as a significant explanatory variable for current volume. In addition the study lends support to Copeland's sequential information model in that for all currencies current trading volume is positively dependent upon previous volume i.e. information flows to traders at different intervals. In the presence of such sequential information dissemination a positive correlation between volume and absolute price change is implied.

Summary

The above reviews demonstrate two main areas which require attention. The first is the need for an objective measure of volatility, although this issue has been latterly addressed to some extent by Lamoureux and Lastrapes (1990), and Najand and Yung (1991). Following these examples, and being mindful of the arguments presented in Section II 1.2, the use of GARCH models would seem more appropriate than that of constructed volatility measures for the analysis of volume-volatility relations in futures markets. Second, studies to date have largely failed to deal adequately with the potential simultaneity problems encountered when modelling contemporaneous volatility and volume data. In order to rectify this short-coming, Chapter 5 of this thesis models the volume-volatility relation as a system using the generalised method of moments (GMM) as provided by Hansen (1982).

CHAPTER 2*

THE EFFECT OF FUTURES TRADING ON SPOT PRICE VOLATILITY

2.1 INTRODUCTION

Since the onset of derivative trading there has been widespread interest in their effect upon prices in the underlying spot markets; this interest has been particularly marked in stock index futures since the 1987 market crash, but has in its history such examples as the banning of onion futures in 1958. The outcome of such interest has led some parties to call for greater restrictions on futures trading. It is often claimed that the onset of derivative trading destabilises the associated spot market, leading to an increase in spot price volatility. Arguments to the contrary, however, state that the introduction of futures trading will stabilize prices and so lead to a decrease in price volatility. The question of volatility is important due to its implications for asset/commodity pricing and portfolio management. Market agents who seek to avoid risk may adjust their portfolios of assets/commodities by reducing their commitments to those markets whose volatilities are unacceptably high. The role of futures markets is to reduce the risks faced by agents from existing volatility by providing a hedging function. If it is found that futures actually increase the inherent volatility of spot prices then their justification for being may be not only nullified but also rebutted. Baumol (1957) suggests, however, that the debate cannot be resolved wholly on a

* The main elements of this Chapter have appeared in Antoniou and Foster (1992a).

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theoretical level and so should be analysed by empirical investigation.[19]

The purpose of this chapter is to empirically investigate the effects of the introduction of a futures contracts for Brent crude oil on price volatility in the related spot market.[20] This investigation benefits from the use of GARCH-type models which are a superior technique for modelling volatility to those techniques utilised in most previous studies of this nature. Preliminary analysis considers a dynamic linear regression model in order to give insights into the possible effects of futures trading. This approach is common to many previous studies and so its use here is to allows comparison with previous studies. In addition, this approach allows comparison of results generated by the more appropriate GARCH technique with those from the more traditional method of investigation. The regression analysis is intended to be illustrative, with the main emphasis of the investigation being the use of GARCH techniques. In addition this study uses the Kalman filter to assess the relative contribution of noise and information trading to price volatility.

In brief we find that on a weekly basis the volatility of the spot market has been affected by futures trading in that the reaction to news has been enhanced while both the short-term and long-term persistence of past volatility has declined. On a daily basis, however, that market has become more volatile in that the short-term persistence of volatility has risen, with this being attributed to noise trading.

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[19] Baumol (1957, p.263) suggests that, "How often and to what extent speculation is stabilizing remains a matter for empirical enquiry."

[20] This analysis cannot be extended to include the NYMEX market for WTI futures due to restrictions on the availability of appropriate data.

The chapter proceeds as follows. Section 2.2 presents the theoretical considerations relevant to the issue of futures markets and their influence on price volatility in the underlying spot market. The section explains how futures markets can influence spot prices, and why increased volatility need not necessarily have a deleterious effect. Section 2.3 gives a detailed explanation of the GARCH procedures which represent the central methodology used in this investigation. In Section 2.4 The Kalman filter procedure is described as applied to signal extraction problems. Section 2.5 provides an explanation of the data used and reports preliminary results from the investigation using regression analysis and constructed measures of volatility. The main empirical findings from this investigation are given in Section 2.6, while Section 2.7 provides a summary and conclusions.

2.2 Theoretical Considerations

The Price Effects of Futures Trading

To fully appreciate the influence of futures on spot markets we must have a proper understanding of the relationship between information and volatility. It is only then that we can adequately and confidently discuss the influence of futures on spot price stability. In this respect it is important to understand *how* futures trading can influence spot prices. In brief, futures trading is expected to detect information not discovered by the spot market, this information will then be transmitted to the spot market where its arrival will manifest itself as more frequent price changes.[21] The reasons as to

[21] It is a clearly established principle that the arrival of relevant information will affect price changes; if the frequency of information arrival is increased then the frequency of price changes should follow suit.

why futures markets will detect such 'additional' information, and its impact on spot price volatility is the subject of this section. Much of the volatility literature to date has carried with it the value judgement that increased volatility in prices is undesirable, and that lower volatility should be the intent. This view is correct, however, only in certain cases, and can be misleading if used as a generalised normative statement.[22] The view that volatility is undesirable *per se* derives from a failure to fully appreciate the association between the rate and type of information flows, and price fluctuations. In efficient markets prices will exhibit a timely response to the arrival of relevant information. If futures markets improve the efficiency of spot markets by enhancing the discovery of information, and the speed at which it is transmitted to the market, then an increase in short-run volatility due to their presence is both a confirmation and a consequence of their beneficial impact on price discovery. In this instance, price volatility is simply the efficient reaction to the improved detection, recognition, and reaction to information. It is only when futures markets provide a medium for noise trading that they bring adverse consequences both for price stability and for the efficient reaction to information.

Spot and futures markets present prices for what is essentially the same commodity. With reference to storable commodities, Telser (1958) demonstrates that futures prices reflect the average expectation of the spot price that will prevail when the futures contract expires. At expiration the spot and futures prices must converge, but prior to that point they will be held together through the cost of carry relationship. It is

[22] Where futures markets induce additional volatility in spot markets due to speculative trading based on noise, then that volatility is indeed undesirable since it does not reflect real information flows.

assumed that the current spot price will change when expectations about future spot prices change. This occurs because the revision in expected price prompts a reallocation of the commodity between storage and current supply. The link between futures markets and spot prices is described thus: futures markets provide a forum in which information can be discovered, and a route through which information can be transmitted. Since the futures price represents expectations of the future spot price, any information it contains will have a potential impact on spot prices. As such futures trading can affect price expectations (and so prices) in spot markets by adding to agents' information sets. The above mechanism will work, however, only when futures markets have the ability to detect information lacking in the spot market.

Cox (1976) suggests that there are least two reasons why futures trading will affect the amount of information reflected in expected spot prices; that they attract additional traders to the commodity market, and that transaction costs are lower in futures markets. The additional body of traders identified by Cox are speculators; this does not imply that speculators are not present in the absence of futures markets, but that futures offer speculators an attractive arena for trading. Given the nature of their trading, and the lower cost of participating in futures, speculators are expected to be better informed than spot traders and so be able to detect information not (yet) detected by the spot market.[23] The second point raised by Cox, and one touched upon above, is that futures markets can produce more informed price expectations due to

[23] Since futures traders are assumed to be better informed than their counterparts in the spot market, the futures price is expected to provide a more accurate prediction of future spot price. It follows that if spot traders are better informed the current spot price will be the most accurate predictor of future spot prices.

them facing fewer transactions costs than the spot market. There may be situations where a trader's expectation about future spot prices differs from those held by other agents, but the cost of communicating such information to the market (through trading) is prohibitively high. Futures markets in this instance present such agents with low cost access to the market, thus allowing their information to enter the public domain.[24]

Improved Efficiency and Volatility

The important question, however, is not whether the introduction of futures trading has led to a change in spot volatility *per se*, but what that change represents. If an observed increase in spot price volatility following the advent of futures trading can be attributed to improved responses to information, then the increased volatility is simply a product of improved price efficiency. In this regard, to label such volatility as destabilising is to attach to it negative connotations which are not deserved. If pre-futures volatility is low due to inadequacies in the speed and scope of information discovery then we should not be surprised if futures trading leads to increased volatility. Thus, volatility increases need not necessarily be damaging but could signal an improvement in the informational efficiency of spot markets. Given the nature of futures i.e. their ease and cheapness of use, gearing characteristics, and dissociation from possession of the underlying commodity, trading on futures markets can be expected to occur much more frequently than on the spot market. As a consequence we can intuitively expect information to be released more quickly, or at less discrete

[24] This point should be of interest to regulators since it highlights the negative effects of regulation aimed at increasing the costs of futures trading.

intervals, in futures markets. Thus, prices will change more frequently in response to the more frequent flow of information; this proposition is given theoretical support later in this section.

Technical Failure and Destabilisation

While the 'destabilising' influence of futures markets may be explained by improvements in the speed and scope of information discovery, futures can have a truly destabilising affect on spot prices if they experience technical failure. Figlewski (1981) reports a number of circumstances under which futures can cause spot price volatility where the root causes of the volatility increases are not due to improved information dissemination. The first of these relates to the possibility that futures themselves may be prone to manipulation which causes price distortions. An example of this could be a market squeeze, causing prices to rise unnecessarily. Second futures may induce a demand for hedge trading without attracting a commensurate supply of liquidity from speculators. Figlewski notes that if such imbalances occur, hedging pressures from the futures market may permeate into the spot market, forcing spot participants to bear risk transferred from the futures market, in addition to existing spot market risk.[25]

Finally, we return to the notion of futures traders being better informed than spot traders. This need not necessarily be the case, since it is possible that in some markets agents involved in the physical commodity to be better informed than futures traders.

[25] The Chicago onion futures contract was banned following claims that speculation induced excessive price volatility in the spot market. Working (1960) suggests that the contract attracted mainly hedge trading and that the volatility was, in fact, due to inadequate speculative activity.

As such, even though futures prices may accurately reflect all information available to the futures market, those prices will be inappropriate and trading based on them will have an adverse influence on spot prices.

A Model of Information and Volatility

Theoretical support for the relationship between information flow and price volatility is provided by Ross (1989), who investigates the effect of information on price and price variability, and specifically the relationship between the timing of information and prices. Essentially, Ross poses the question as to whether the *speed* of information release affects prices in an efficient market. The study considers an example where the increased speed of information revelation (uncertainty resolution) affects prices due to its favourable impact on investment decisions, and so ultimately on cash flows.

Ross utilises the no-arbitrage methodology developed by Ross (1976), and Cox and Ross (1976) to examine the link between asset prices, p, and the flow of information, s, both of which are assumed to follow diffusion processes;

$$\frac{dp}{p} = \mu_p dt + \sigma_p dz_p \qquad (2.1a)$$

$$\frac{ds}{s} = \mu_s dt + \sigma_s dz_s \qquad (2.1b)$$

where μ and σ represent the mean and standard deviation respectively
z is a normally distributed random variable with zero mean and unit variance

Thus the rate of change of the variable (price or information) is a function of the rate of change in its mean, together with its variance (standard deviation). From the above Ross develops a differential equation which is simplified to obtain the expression;

$$\sigma_p dz_p = \sigma_s dz_s \tag{2.2}$$

This then implies equation (2.3) below which forms Ross' Theorem 2, that the variance of price change is equal to the variance (rate) of information flow;

$$\sigma_P^2 = \sigma_S^2 \tag{2.3}$$

where σ_p^2 is variance of price
σ_s^2 is variance (rate) of information flow

The relationship in equation (2.3) assumes efficient markets and is derived as a consequence of there being no arbitrage; the implication being that if the equality does not hold then arbitrage will be possible. Given the equality in equation (2.3), Ross is able to conclude that the volatility of prices is directly related to the rate of flow of information. In essence this model implies that unless the flow of information is constant, price volatility will vary through time, and will vary depending upon the rate as well as the type of information flow. It is this point which is the crux of the volatility debate, since if the presence of futures leads to an increase in the rate of flow of information then an associated increase in volatility may be beneficial.

The contribution of Ross' analysis goes further than providing a conceptual link between information flows and price volatility, however. It also outlines the connection between the volatility and efficiency literatures. This connection being that both enhanced efficiency and increased short-run price volatility are directed by the same variable; the improvement in information detection. This point is given a more thorough treatment in Section 2.6.

Noise and Volatility

Much of the discussion so far has assumed that futures markets improve the revelation and impounding of information, so leading to increased price volatility which is attributable to efficiency improvements. It is now appropriate to consider a less salutary influence of futures; the transfer of noise-induced volatility to spot prices.

In general the empirical literature on volatility effects has not distinguish between the information and noise components of price variability. Powers (1970), however, approaches the subject by trying to assess the effects on the noise component of price fluctuations, σ_n^2, of futures trading, postulating a null hypothesis that derivative trading reduces noise. By entertaining the possibility that prices can change in response to noise, Powers describes the total variation in prices as the sum of the variation in a systematic component, *i*, representing information, and a random or error element, *n*, representing noise.

$$\sigma_p^2 = \sigma_i^2 + \sigma_n^2 \tag{2.4}$$

where σ_p^2 is price volatility
σ_i^2 is the information flow
σ_n^2 is noise

The above is essentially equivalent to the model provided by Ross (1989), indeed in Ross' arbitrage-free model market efficiency would imply that $\sigma_n^2 = 0$, equating equations (2.4) and (2.3). If $\sigma_n^2 \neq 0$ then prices will exhibit random fluctuations which cannot be explained by changes in underlying fundamentals. Moreover, if the value of σ_n^2 increases after the onset of derivative trading then any observed increase could be attributed to increased noise. Application of the Kalman filter to the spot price volatility series allows us to investigate the information and noise components of volatility. This procedure is detailed in Section 2.4 following a description of the GARCH techniques used to model the volatility of spot prices.

2.3 GARCH ANALYSIS

Volatility and Univariate GARCH

The main methodological improvement of this investigation is the use of univariate GARCH techniques to analyse changes in both the size and nature of price volatility. The interest in GARCH stems from dissatisfaction with the use of constructed measures of volatility, together with the inadequacies of standard least squares regression for testing volatility. The use of constructed measures of volatility is unsatisfactory due to the inherent subjectivity in the choice of measures, combined with the lack of formal statements as to the appropriateness of those measures. This problem is compounded by findings which suggest that tests of volatility are sensitive to the measure of volatility selected, see for example Board and Sutcliffe (1990). In addition, OLS procedures implicitly assume homoskedasticity in price changes. This can be a misleading assumption given the well documented tendency for speculative prices to exhibit heteroskedasticity, see Bollerslev, Chou and Kroner (1992). The heteroskedasticity of speculative prices is not only a recognised empirical regularity, but also finds support in Ross' model of price volatility and information flow as discussed in the previous section. In fact, unless we make the strong assumption that the flow of information onto the market is constant, price changes will inevitably be heteroskedastic. As discussed in Chapter 1, some recent studies dealing the volatility question, (see for example Baldauf and Santoni (1991), Antoniou and Foster (1992)) have recognised the limitations of the traditional approach and responded by using empirical techniques which directly model volatility, namely GARCH-type models. The GARCH class of models describe the temporal dependence of conditional second moments in a fashion analogous to that of ARMA models and conditional first moments. The models use the conditional variance rather than the unconditional variance and so offer similar gains to those achieved from using the conditional mean rather than the unconditional mean.

In his seminal paper, Engle (1982) introduces the notion of an autoregressive conditional heteroscedastic (ARCH) model as a way of modelling time-varying variance. An ARCH model possesses an error term which is serially uncorrelated with zero mean, and while its unconditional variance is constant, its conditional variance time-varies. The notion underlying Engle's ARCH is that the variance of a process is subject to change such that the price change at time t is conditional on the change (but not sign of the change) at t-1. In this fashion the conditional variance is allowed to change over time as a linear function of past squared innovations. Thus, a simple univariate model with errors that follow an ARCH(q) process will have the following representation:

$$X_t = \alpha + \beta Y_{t-1} + \epsilon_t \qquad \epsilon_t \sim N(0,h_t) \tag{2.5}$$

$$h_t = a_0 + \sum_{i=1}^{q} a_i \epsilon_{t-i}^2 \tag{2.6}$$

It follows that an ARCH model can provide a description of the temporally evolving conditional variance. Thus, by estimating an ARCH model one can solve for the implied time series of conditional second moments, and so derive a measure of volatility.

Bollerslev (1986), extended Engle's ARCH to a generalized ARCH or GARCH process. With GARCH the conditional variance is modelled as a linear function of the lagged conditional variance in addition to the past error variances contained in ARCH representations. A GARCH(p,q) process is represented as:

$$h_t = a_0 + \sum_{i=1}^{q} a_i \epsilon_{t-i}^2 + \sum_{j=1}^{p} b_j h_{t-j} \tag{2.7}$$

In this study oil returns are modelled directly as a GARCH process; the ARCH representation is not considered since it is implicit in the more general GARCH.

Further extensions of GARCH which are of interest here are the (G)ARCH-in-Mean (GARCH-M), and integrated GARCH (I-GARCH) models. The ARCH-M model is attributed to Engle, Lilien and Robins (1987), with its generalisation as GARCH-M being subsequently used by Bollerslev, Engle and Wooldridge (1988). Essentially (G)ARCH-M differs from (G)ARCH in that the conditional variance (h_t) is included as an explanatory variable in the mean equation. In the case of a (G)ARCH-M model, therefore, the conditional variance is not only heteroskedastic, but the standard deviation of each observation is a determinant of the conditional mean of that observation. This has the implication that changes in the conditional variance will be associated with changes in the conditional mean. Under GARCH-M equation (2.5) could be rewritten:

$$X_t = \alpha + \beta Y_{t-1} + \delta h_t + \epsilon_t \tag{2.8}$$

where h_t is as in equation (2.7).

GARCH-type models provide a way of formalising the commonly observed clustering of volatility in price series; large price changes being followed by large changes, and small changes by small changes of either sign[26]. Such volatility clustering is particularly well illustrated in Figure 2.3.

Volatility Persistence and I-GARCH

Engle and Bollerslev (1986), introduce a further extension to GARCH in which the model specification is characterised by nonstationary variances. In situations where such a model applies, any shock to the variance of the process is permanent. The model, referred to as integrated GARCH or I-GARCH, may be thought of as the variance equivalent of a unit root in the conditional mean. The GARCH(1,1) specification (alone) has the interesting property that shocks to volatility decay at a

[26] Observations on the tendency of financial data series to exhibit volatility clustering are largely attributed to the works of Mandelbrot (1963) and Fama (1965).

constant rate, with the speed of decay determined by the sum of a_1 and b_1. This property is analogous to the value of the serial correlation coefficient in an AR(1) process, in that in both cases a (sum of) parameter value(s) of unity indicates that shocks will persist *ad infinitum*. It follows that the nearer the value of $a_1 + b_1$ to unity, the longer shocks to volatility will persist into the future. In contrast to a stationary process, therefore, shocks to volatility in an I-GARCH process will persist until the arrival of the next shock. To demonstrate we may take a GARCH (1,1) model and impose the condition $a_1 + b_1 = 1$. With this condition the model specification can be represented as:

$$h_t = a\epsilon_{t-1}^2 + (1-a)h_{t-1} \tag{2.9}$$

where $0<a<1$

Engle and Bollerslev demonstrate that it follows from the above model that:

$$E(h_{t+s}) = h_t \tag{2.10}$$

Hence the conditional variance s periods into the future will be the same as the current conditional variance. In this way the I-GARCH model is seen to be closely related to a unit root in the conditional mean; shocks to the system are permanent. It should be noted, however, that there is as yet no clear test for integration in the variance. Despite this Engle and Bollerslev (1986) note that Dickey-Fuller tests can be used, and that on the basis of Monte Carlo experiments they do appear to be well behaved.

2.4 State Space and the Kalman Filter

The Concept of State Space

A system can be thought of as comprising three elements; input signals, state variables, and output variables. State models of systems identify the dynamics and interaction of these variables. On an intuitive level, the state variables represent the initial internal conditions of a system which, in conjunction with the input variables, determine the system's outputs. As such analysis of state systems rests on the premise that knowledge of the input signals over time, t_0 - t_∞, together with knowledge of the initial states at t_0, allows the determination of the output signals as they evolve over time, t_0 - t_∞.

Formally defined the *state* of a dynamic system is the minimum set of state variables sufficient to completely describe the system's outputs given the system's inputs. The state variables represent the cumulative effect of all past inputs to the system and as such are fundamental in determining the future evolution of the system. The set of n state variables needed to completely describe the behaviour of a system is referred to as the state vector. The state vector is updated at each time interval to reflect new information about the future. To achieve this state space utilises measurement and transition equations which can be illustrated in general form for a multivariate time series, $\mathbf{Y}_t$, as follows;

$$Y_t = Z_t \Psi_t + \epsilon_t \tag{2.11}$$

Measurement equation

$$\Psi_t = T\Psi_{t-1} + \eta_t \tag{2.12}$$

Transition equation

In the measurement equation $\mathbf{Y}_t$ is the n×1 vector of endogenous variables, $\mathbf{Z}_t$ is an n×m matrix of predetermined variables and ε_t is an n×1 vector of serially uncorrelated error terms with zero mean and covariance matrix, $\mathbf{H}_t$. The measurement equation relates the state vector, Ψ_t, to the time series of observed variables $\mathbf{Y}_t$. In the transition equation $\mathbf{T}$ is an m×m matrix and η_t is a g×1 vector of serially uncorrelated error terms with zero mean and covariance matrix, $\mathbf{Q}_t$.The transition equation describes the evolution of the state vector in response to new information by specifying how the forecast error feeds back into the state vector for updating. The application of the Kalman filter to the state space form is discussed in the next section.

The Kalman Filter

The Kalman filter is a set of equations which provide a means of estimating the unobservable or the changing nature a dynamic system expressed in state space form. The Kalman filter procedure is particularly useful in regard to two modelling issues; signal extraction problems, and time-varying parameter estimation. In the case of signal extraction problems, we are faced with an unobservable components model of the type in equation (2.13) below. Here $\mathbf{Y}_t$ is an observed series which is assumed to consist of unobserved components, $\mathbf{Y}_t^*$, representing the signal to be extracted, plus an error term ε_t. The Kalman filter provides an optimal estimator of the state vector $\mathbf{Y}_t^*$ based upon the most recent, sequentially updated information on $\mathbf{Y}_t$.

$$Y_t = Y_t^* + \epsilon_t \tag{2.13}$$

The second modelling issue amenable to estimation using this technique is for time-varying models, as illustrated in equation (2.14) below $\mathbf{Y}_t$ and $\mathbf{X}_t$ are observable and the Kalman filter is used to generate a recursive estimator for α_t, which represents the state vector of time-varying coefficients.

$$Y_t = X_t \alpha_t + \epsilon_t \tag{2.14}$$

In this chapter the Kalman filter is used for signal extraction as a means of identifying the noise trading element of volatility. The procedure is given a more detailed treatment with respect to this application below. Chapter 4 also utilises the Kalman filter but for time-varying parameter estimation, and accordingly deals with this particular application in greater detail.

The Kalman filter, as applied to a state space representation, is a recursive procedure for updating the estimator of the state vector as new observations become available, and is applied as a two stage process. The first stage involves the use of prediction equations to form an optimal predictor of the next observation in the dependent variable series, $\mathbf{Y}_t$, based upon all information currently available. Once the true value of the new observation in $\mathbf{Y}_t$ is revealed, the second stage of the procedure utilises the updating equations to combine this observation with the estimator of the state vector. This procedure is presented in greater detail below for the general case of a multivariate time series.

Once a system has been transformed into state space form, such as that described in equations (2.11) and (2.12), the Kalman filter can be applied to estimate its unknown parameters as follows. Utilising past values of the dependent variable up to and including $\mathbf{Y}_{t-n}$, the prediction equation provides the optimal estimator, ($\psi_{t-n+1|t-n}$) of the next-period state vector, Ψ_{t-n+1}. Once the next-period value of the dependent variable, $\mathbf{Y}_{t-n+1}$, is revealed, the estimator of the state vector is updated through the updating equation. In this way the estimator is adjusted as new information arrives. This process is explained below with the presentation generally following that of Harvey (1989, chapter 3) but using notation consistent with this study.

Returning to the state space model described in equations (2.11) and (2.12), we may denote ψ_{t-1} as the optimal estimator of the state vector, Ψ_{t-1}, at time period t-1. Furthermore, at time period t-1 the optimal estimator of the current state vector, Ψ_t, is given by $\psi_{t|t-1}$ where,[27]

$$\psi_{t|t-1} = T_t \psi_{t-1} \tag{2.15}$$

From the above association we may define ρ_{t-1} as the mxm covariance matrix of the estimation error such that;

$$\rho_{t-1} = E[(\Psi_{t-1} - \psi_{t-1})(\Psi_{t-1} - \psi_{t-1})'] \tag{2.16}$$

The current value of this covariance matrix, ρ_t, is given by;

[27] The form of equation (2.15) is analogous to the transition equation (2.12).

$$\rho_{t|t-1} = T_t \rho_{t-1} T_t' + Q_t \tag{2.17}$$

Equations (2.15) and (2.17) are collectively known as the prediction equations, while their respective updating equations are given in equations (2.18) and (2.19).

$$\psi_t = \psi_{t|t-1} + \rho_{t|t-1} X_t' I_t^{-1} (Y_t - X_t \psi_{t|t-1}) \tag{2.18}$$

$$\rho_t = \rho_{t|t-1} - \rho_{t|t-1} X_t' I_t^{-1} X_t \rho_{t|t-1} \tag{2.19}$$

At each period there will be a prediction error between the estimate of $\mathbf{Y}_t$ made in the previous period, and its actual value. The prediction errors, or innovations, are responsible for the way in which ψ_t is updated. Defining $\mathbf{V}_t$ as a (mean zero) vector of innovations, $\mathbf{I}_t$ is the innovation covariance matrix and is defined as;

$$I_t = X_t \rho_{t|t-1} X_t' + H_t \tag{2.20}$$

The Kalman filter can be utilised from this point by supplying initial estimates for ψ_0 and ρ_0, together with $\mathbf{T}$, which for practical purposes can be represented by an identity matrix if we are to allow the time-varying parameters to evolve as a random walk. With the initial conditions set, the Kalman filter will generate an estimate of the state vector and will update this estimate with the arrival of each new observation.

Kalman Filter for the Identification of Noise Trading

As mentioned briefly above, one application of the Kalman filter is for signal extraction, or the extraction of unobservable components from a system. It is this particular application which is utilised in this chapter in order to identify volatility attributable to noise trading. We can, however, only directly observe price volatility itself, and so cannot distinguish between that which is attributable to the flow of information and that which is driven by noise. Our goal here, therefore, is to extract a variable assumed to represent information-driven price volatility such that the residual volatility may be considered to be attributed to noise trading.

Following the models due to Powers (1970) and Ross (1989) outlined above, it is established that a price volatility series will consist of two components; an information component and a noise component[28]. To motivate this analysis, we make the further assumption that information arrives onto the market in a purely random fashion, and represent this behaviour as a random walk. In this way we propose to decompose the volatility series into an unobserved information component, and a noise component represented by an error term. The task of removing the information component of observed price volatility represents a signal extraction problem where information-induced volatility is the signal to be extracted and noise is the residual. Let the scalar h_t be the time series of observed price volatility, which is assumed to consist of the unobserved information component h_t^*, and the noise term, n_t, which is expected to be a white noise error term when markets respond to information efficiently. These components constitute the measurement equation from the Kalman filter and can be specified as follows;

[28] This notion also receives the support of Black (1986), who argues that the price of an asset reflects both the information that information traders trade on, and the noise that noise traders trade on.

$$h_t = h_t^* + n_t \tag{2.21}$$

The underlying hypothesis of this analysis is that the noise component should not change following the introduction of futures trading. Any significant changes, however, will imply that noise trading has changed following futures trading. Any such effect can be ascertained once the information-induced component of volatility is extracted from the volatility series. From equation (2.21) we specify the transition equation for h_t^* as;

$$h_t^* = \Theta h_{t-1}^* + \epsilon_t \tag{2.22}$$

In this case Θ is a scalar which assumes a value of unity given that information is assumed to arrive stochastically. It is assumed that an inspection of the nature of the residual noise component of price volatility we enable inferences to be made regarding changes in noise-volatility due to futures trading.

To summarise the state space representation, the measurement equation (2.21) defines price return volatility as the sum of information-induced volatility and noise-induced volatility, while the transition equation (2.22) defines the temporal evolution of information flow. The Kalman filter will provide sequentially updated estimates of h_t^* based upon information about the volatility component as the latter becomes available. To achieve this we must have some prior notion as to how h_t^* varies over time; in this case the specification of equation (2.22) implicitly assumes that information arrives as a random walk following Ross' model.

2.5 Data and Preliminary Analysis

The Data

Weekly constructed volatility series were calculated from daily spot closing prices for Brent crude oil. The data set consists of 238 weekly observations from January 1986 to July 1990. Brent Crude oil futures were established on the IPE in June 1988. As such the sample period represents 129 observations before futures trading and 109 observations thereafter.

Following *inter alia*, Engle (1982), Diebold & Nerlove (1989), and Schwert & Seguin (1990) the data set used in GARCH estimations consisted of daily returns for oil spot prices, with the weekly returns data set based upon the weekly arithmetic mean of the daily levels data. With GARCH analysis one aims to model directly the heteroskedasticity in the variance of a price series, hence the choice of dependent variable. The same sample period as used for the constructed volatility series is used to calculate weekly returns for the GARCH analysis. For GARCH estimations using daily data for Brent crude, spot price returns were calculated from 6th January 1986 to 27th July 1990. The whole sample consists of 1190 observations; 645 observations before the onset of futures trading and 545 observations thereafter. The time series are illustrated in Figures 2.2 and 2.3.

Preliminary investigation using regression analysis considers six different measures of volatility in order to assess any test sensitivity to the measure of volatility used. The first five measures listed below were adopted (for daily data) by Board & Sutcliffe (1991). The measures used are as follows, where T denotes an average weekly price, and t denotes a daily closing price.

1) weekly price range, i.e. highest daily price minus lowest daily price during the week; $(S_{t\ high} - S_{t\ low})$.

2) absolute weekly average price change, i.e. $|S_T - S_{T-1}|$

3) squared weekly average price change, i.e. $(S_T - S_{T-1})^2$

4) absolute log of weekly average price relative, i.e. $|\ln(S_T / S_{T-1})|$

5) squared log of weekly average price relative, i.e. $[\ln(S_T / S_{T-1})]^2$

6) the Figlewski (1981) volatility measure;

$$V_T = \sqrt{\frac{1}{N}\sum_{t=1}^{N} (S_t - S_{t-1})^2}$$

where V_T is volatility in week T
S_t is spot price on day t
N is the number of trading days per week

For illustrative purposes the Figlewski volatility series for Brent crude oil is presented in Figure 2.1 below. Casual observation of Figure 2.1 does not, incidentally, reveal any obvious change in the level of spot price volatility.

Figure 2.1

Weekly Constructed Volatility of Brent Crude Spot Prices

January 1986 to July 1990

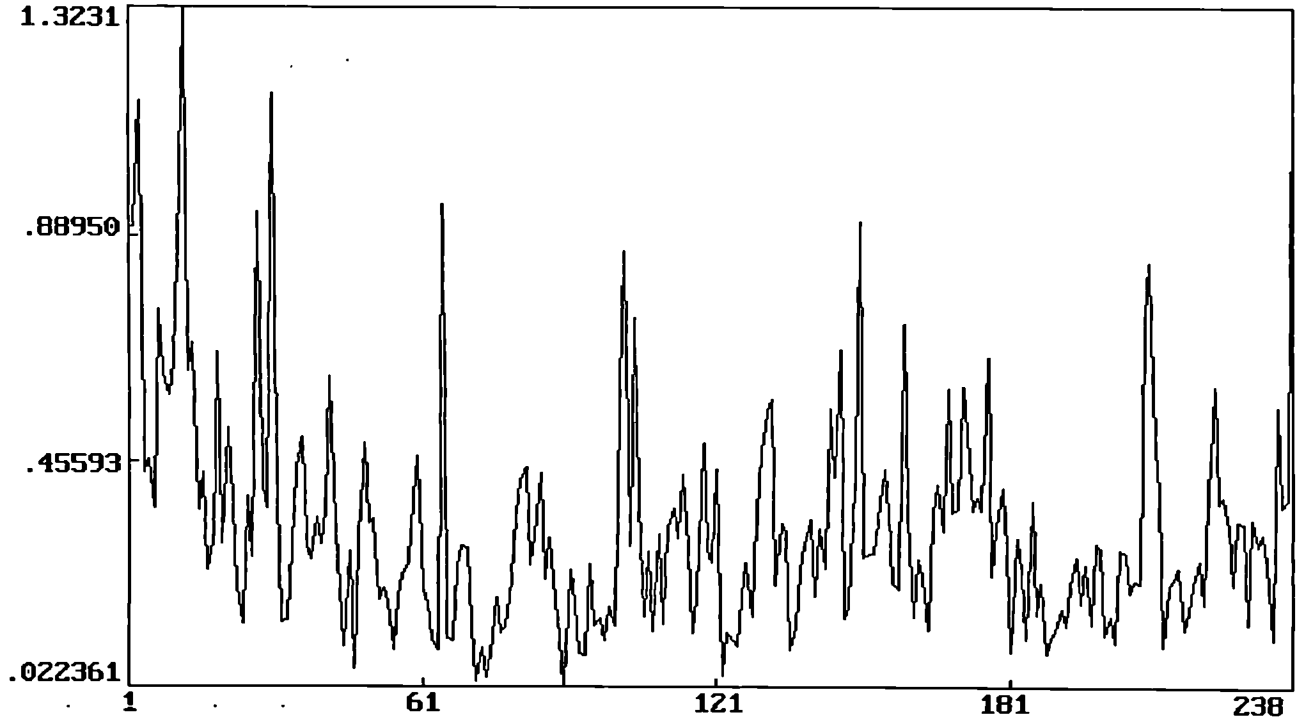


Figure 2.2

Weekly Brent Crude Spot Returns

January 1986 to July 1990

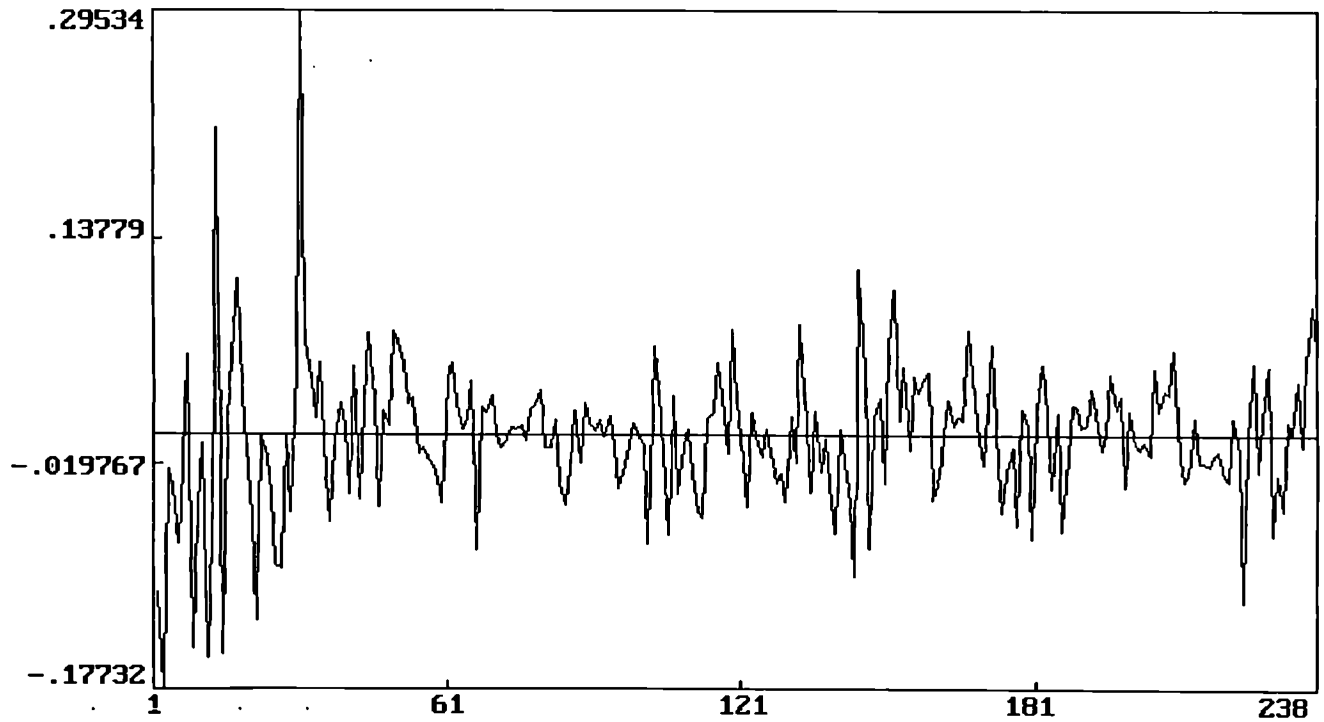
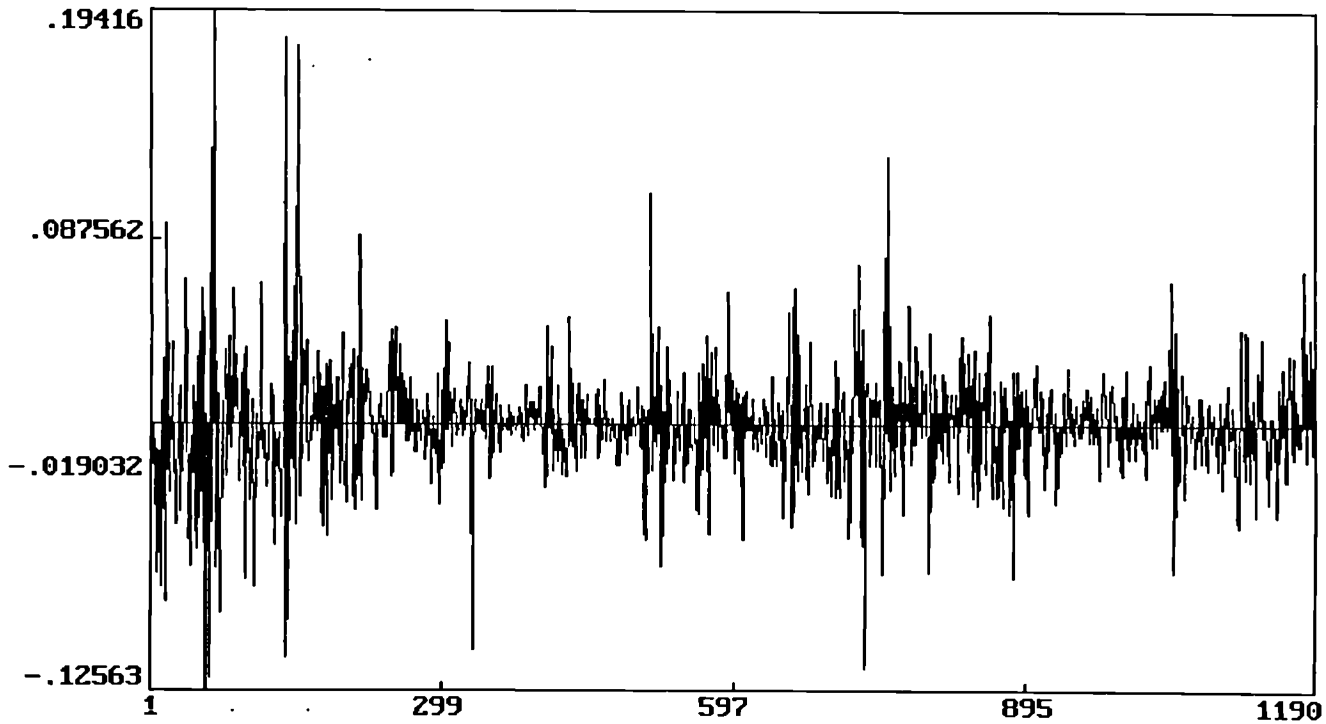


Figure 2.3

Daily Brent Crude Spot Returns

January 1986 to July 1990



Regression Analysis.

A general dynamic linear regression model was constructed to explain spot volatility. Preliminary model specifications included a dummy variable introduced to account for the onset of futures trading and proxy variables to account for general market volatility. The proxy variables nominated (for which there was no futures trading), were gold and a number of commodity indices[29]. The coefficients on the dummy for the onset of futures trading and on all proxy variables were found to be insignificant. The failure to find a statistically significant proxy means that the analysis is necessarily crude since it is not possible to separate the futures listing from other changes which may have impacted on the volatility of the market. A well specified, parsimonious model was generated for each measure of volatility for the entire period. All models were found to be adequately represented by an AR(1) process, except that based on the Figlewski volatility series which marginally accepted an AR(2) specification.

In order to determine any impact of futures trading on volatility, Chow tests were carried out on all models over the whole period to check for structural change. The tests confirmed that there was no structural change after the introduction of futures trading, i.e. that each model's coefficients had not changed substantially between the pre-futures and post-futures periods. In general these results were not sensitive to the measure of volatility used, the only exception being the weekly price range which suggested a structural change, see Table 2.1. Results from the regression analysis of

[29] The connection between gold and oil has been noted by Melvin & Sultan (1990). This study used London Gold Bullion prices. The index measures were Reuters Commodity Index and Moody's Commodity Index. The use of a oil products such as gasoline and gasoil were considered as proxies, but since crude oil and suitable oil products are so closely related the proxies filter specific as well as general influences.

constructed measures of volatility are thus interpreted as providing *prima facia* evidence that the onset of derivative trading had not influenced spot price volatility.

As noted by Harris (1989), the insignificance of the proxy variables raises obvious questions as to the reliability of inferences made about the impact of derivative trading on volatility, since changes could be due to a number of other factors. Difficulties with filtering the effects of other determinants are, however, a common problem experienced by numerous other studies. The techniques for resolving this problem have also been questioned by Edwards (1988a, 1988b), who contends that the use of proxies implies an unacceptable assumption of market segregation. Thus, whilst it is important to realise that inferences made from empirical results must be evaluated with caution, it is recognised that no satisfactory alternative is apparent.

Preliminary GARCH Models

As a precursor to the comparison of GARCH models between the two sub-periods the study modelled the full sample as a GARCH-M process for both weekly and daily data frequencies. A dummy variable was included in the GARCH equation for the onset of futures trading. The weekly data suggested a GARCH-M (1,1) for full sample, while the daily data was adequately represented by a GARCH model. In both cases the dummy for futures trading was found not to be significant suggesting that the size of spot market volatility had not been significantly affected. This observation does not, however, mean that the nature of volatility has not changed. Results are reported in Table 2.2 below.

Table 2.1

Chow Tests for Structural Change in Volatility Models

Volatility Measure	Brent Spot
$S_{t\ high} - S_{t\ low}$	3.26†
$\lvert S_T - S_{T-1} \rvert$	2.39
$(S_T - S_{T-1})^2$	2.65
$\lvert \ln(S_T / S_{T-1}) \rvert$	2.66
$[\ln(S_T / S_{T-1})]^2$	2.32
Figlewski	0.42

† indicates structural change between the two periods
Critical value at 5% = 3.04

GARCH Results from Weekly Data

The primary stage of analysis using GARCH requires the identification of an adequate and parsimonious GARCH representation for the data. This was achieved by estimating a number of GARCH-M(p,q) equations for all combinations of p=1,2,3 and q=1,2,3 for weekly data. This practice aims to ascertain whether the order of GARCH model has changed between the two periods as a way of indicating a change in volatility characteristics. Changes in volatility can be inferred from both changes in the order of the GARCH model, and from changes in the estimated parameters of the model. On the basis of log likelihood tests[30] a GARCH-M(1,1) was found to be the most appropriate representation for both pre-futures and post-futures price series measured on a weekly basis. This model is given in equations (2.23) and (2.24) below,

$$\Delta S_t = \alpha + \delta h_t + \epsilon_t \tag{2.23}$$

$$h_t = a_0 + a_1 \epsilon_{t-1}^2 + b_1 h_{t-1} \tag{2.24}$$

where ΔS_t represents spot price returns

The same proxy variables as used in the OLS regression were introduced into the mean equation for GARCH. The proxies were found to be insignificant in all cases. Table 2.3 illustrates the test results obtained from the GARCH analysis of weekly Brent returns.

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[30] See Akgiray (1989).

Table 2.2

Full Sample GARCH Estimations with Dummy for Onset of Futures Trading

$$\Delta S_t = \alpha + \delta h_t + \epsilon_t$$

$$h_t = a_0 + a_1\epsilon_{t-1}^2 + b_1 h_{t-1} + \gamma D$$

GARCH Coefficient	Brent Spot	
	Weekly	Daily
α	0.002 (0.657)	-.017† (-.427)
δ	3.263 (2.097)	–
a_0	.023† (1.677)	0.155‡ (5.529)
a_1	0.273 (3.371)	0.189 (9.019)
b_1	0.652 (7.411)	0.805 (43.568)
γ	0.012† (0.986)	0.067‡ (2.239)

†Figures multiplied by 10^2 for readability. ‡Figures multiplied by 10^4 for readability. Figures in parentheses are *t*-statistics. D is the dummy for futures trading. It is noted that the standard errors may be biased downwards due to possible non-normal residuals.

GARCH-M Model for Weekly Brent Returns

$$\Delta S_t = \alpha + \delta h_t + \epsilon_t$$

$$h_t = a_0 + a_1 \epsilon_{t-1}^2 + b_1 h_{t-1}$$

GARCH Coefficient	Brent Spot	
	Pre-futures	Post-futures
α	-0.764† (2.489)	-0.026 (2.000)
δ	15.637 (4.459)	7.943 (2.325)
a_0	0.645‡ (3.981)	0.269† (2.360)
a_1	0.146 (6.636)	0.269 (2.300)
b_1	0.837 (44.053)	0.697 (7.112)
a_1+b_1	0.98	0.96

†Figures multiplied by 10^2 for readability. ‡Figures multiplied by 10^4 for readability.
Figures in parentheses are *t*-statistics

Given that the order of GARCH model was unchanged over the two periods we proceed to test for change in the estimated GARCH coefficients. This permits us not only to test for changes in the magnitude of volatility, but also to examine any changes in the nature of volatility. To this end the null hypothesis that the GARCH parameters were equal for both periods was tested. On the basis of F-tests, the null hypothesis of no change in the parameters was strongly rejected in all cases.

The statistical adequacy of the model specification was tested using the Ljung-Box statistic for heteroskedasticity and serial correlation in the GARCH residuals. Results attested to the adequacy of the models' specification; results are reported in Table 2.4. In addition to these findings a number of important observations may be made from the results obtained. First the pre-futures model and the post-futures model are candidates for an I-GARCH specification, with the parameters a_1 and b_1 in the pre-futures model summing to .98 and the post-futures parameters summing to .96. Dickey-Fuller (ADF) tests were carried out on the volatility series generated from the GARCH models, h_t, to test for an I-GARCH specification. The tests reveal that whilst the pre-futures sample was integrated the post-futures model was stationary. This observation implies that the persistence of shocks has decreased since the onset of derivative trading. Second, the coefficient on the conditional variance (δ) in the mean equation (2.23) has substantially reduced in the post-futures sample suggesting that spot returns volatility is less important in explaining spot returns after the advent of futures trading. This phenomena can be explained with the hedging opportunities which futures offer; once agents are given the ability to hedge their positions, the volatility of oil prices will have much less effect upon the price itself.

Finally, the parameters of the lagged square error (a_1) and the lagged conditional variance (b_1) of the GARCH representation (equation (2.24) have experienced statistically significant changes since the onset of derivative trading. While a GARCH(1,1) process is maintained, the parameters of the GARCH process have undergone quite substantial changes. The value of a_1 has increased which, in an ARCH representation, would suggest an increase in volatility[31]. The lagged conditional variance parameter has, however, decreased.

The increase in the ARCH parameters is interpreted as showing an increase in informational efficiency in the spot market due to the information content of futures prices. This increased efficiency will lead to a greater reaction to news as suggested by the increase in the a_1 "news" coefficient. The coefficient a_1 relates innovations in the previous period to current changes in the spot price. Thus it follows that as the value of a_1 rises the impact of recent news will have a greater effect on current prices. This suggests that more information is being impounded into prices in the post-futures period. The decrease in the lagged conditional variance term (b_1) is taken here as evidence that the short-run persistence of volatility is considered less important in the post futures period, presumably because markets are becoming more efficient on a weekly basis.

[31] See Baldauf & Santoni (1991).

Table 2.4

GARCH-M Model Test Statistics (Weekly)

Test	Brent Spot	
	Pre-futures	Post-futures
Heteroskedasticity		
Lag 1	0.05	0.43
2	1.16	0.99
3	1.16	1.01
4	1.16	2.47
Autocorrelation		
Lag 1	2.09	3.76
2	2.13	3.76
3	5.62	5.59
4	5.94	6.16
Integration	-2.07	-26.52

Tests for heteroskedasticity and autocorrelation are Ljung-Box statistics and are χ^2 distributed. Critical values at 5% are 3.84, 5.99, 7.81, and 9.49 for lags of 1, 2, 3, and 4 respectively. Test for integration is an ADF test with a critical value at 5% =-2.86.

GARCH Results from Daily Data

As with the weekly data set, GARCH(p,q) representations for the daily data set were estimated for all combinations of p=1,2,3 and q=1,2,3. Log likelihood tests demonstrated both the pre-futures and post-futures periods to be adequately represented by a GARCH(1,1) specification. Proxy variables were again found to be insignificant in all cases. Table 2.5 illustrates the results obtained from the GARCH analysis of daily returns. Integration is tested using I-GARCH and for the pre-futures period the coefficients a_1 and b_1 sum to .98, while the corresponding figure for the post-futures period is .97. ADF tests carried out on the volatility series generated by the GARCH models reveal them to be stationary. Results are reported in Table 2.5.

For daily data the impact of recent news is seen to have a lesser effect on prices in the post-futures period. This is evidenced by the decline in the value of a_1 in the post-futures period, suggesting that prices are less responsive to more recent news information. Moreover, the parameter on the lagged conditional variance, b_1, is larger in the post-futures period suggesting an increase in the short-term persistence of volatility. Explanations for these findings are provided in the next section.

A final observation is that while the weekly data is described by a GARCH-M model, the use of daily data suggests a GARCH representation. This observation can be explained with reference to hedging activity. As illustrated in Section 2.3, GARCH-M relates the conditional variance to the conditional mean. The influence of the variance on the mean can be attributed to hedgers adjusting their positions in light of changing volatility. Thus, if volatility (and so risk) increases, then hedge traders will buy or sell futures in order to cover their spot positions. Such trading will clearly lead to a change in the price of futures contracts and so to changes in the spot price; the change in spot price is assured by arbitrage relationships implicit in the cost of carry theory. On a weekly basis we can expect traders to respond to changing volatility by adjusting their hedged positions. On a daily basis, however, this is unlikely to be the case, hence the model for daily data is not GARCH-M.

Noise and Volatility

Having isolated the noise component of volatility we compare its character before and after the onset of futures trading both by casually observing a plot of the noise variable, and by comparing the variance of that variable over the two periods. Changes in the nature of noise-induced volatility are inferred from the number of times which the noise variable exceeds its two standard deviation boundaries. In order to allow proper comparison of the sub-periods the first 100 observations are trimmed from the pre-futures sample so that each period has an equal number of observations. The noise variable is observed to cross the two standard deviation bounds with greater frequency and to a greater extent in the presence of a futures market; this can be seen from Figure 2.4. Similarly the variance of the noise variable increase from .114E-7 before futures to .151E-7 afterwards. From these results we infer that noise trading has increased in the post-futures period, and assume that the primary explanation for the increase in short-term volatility and decrease in reaction to news lies with traders responding to noise rather than information on a daily basis.[32]

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[32] Noise is not considered for weekly data since it is regarded as not likely to have an effect upon lower frequency trading.

Table 2.5

GARCH Model for Daily Brent Returns

$$\Delta S_t = \alpha + \epsilon_t$$

$$h_t = a_0 + a_1\epsilon_{t-1}^2 + b_1 h_{t-1}$$

GARCH Coefficient	Brent Spot	
	Pre-futures	Post-futures
α	0.014† (0.331)	-0.631‡ (-0.072)
a_0	0.143‡ (4.166)	0.145‡ (3.519)
a_1	0.229 (8.127)	0.082 (5.171)
b_1	0.753 (29.773)	0.887 (42.930)
a_1+b_1	0.98	0.97

†Figures multiplied by 10^2 for readability. ‡Figures multiplied by 10^4 for readability.
Figures in parentheses are t-statistics

Table 2.6

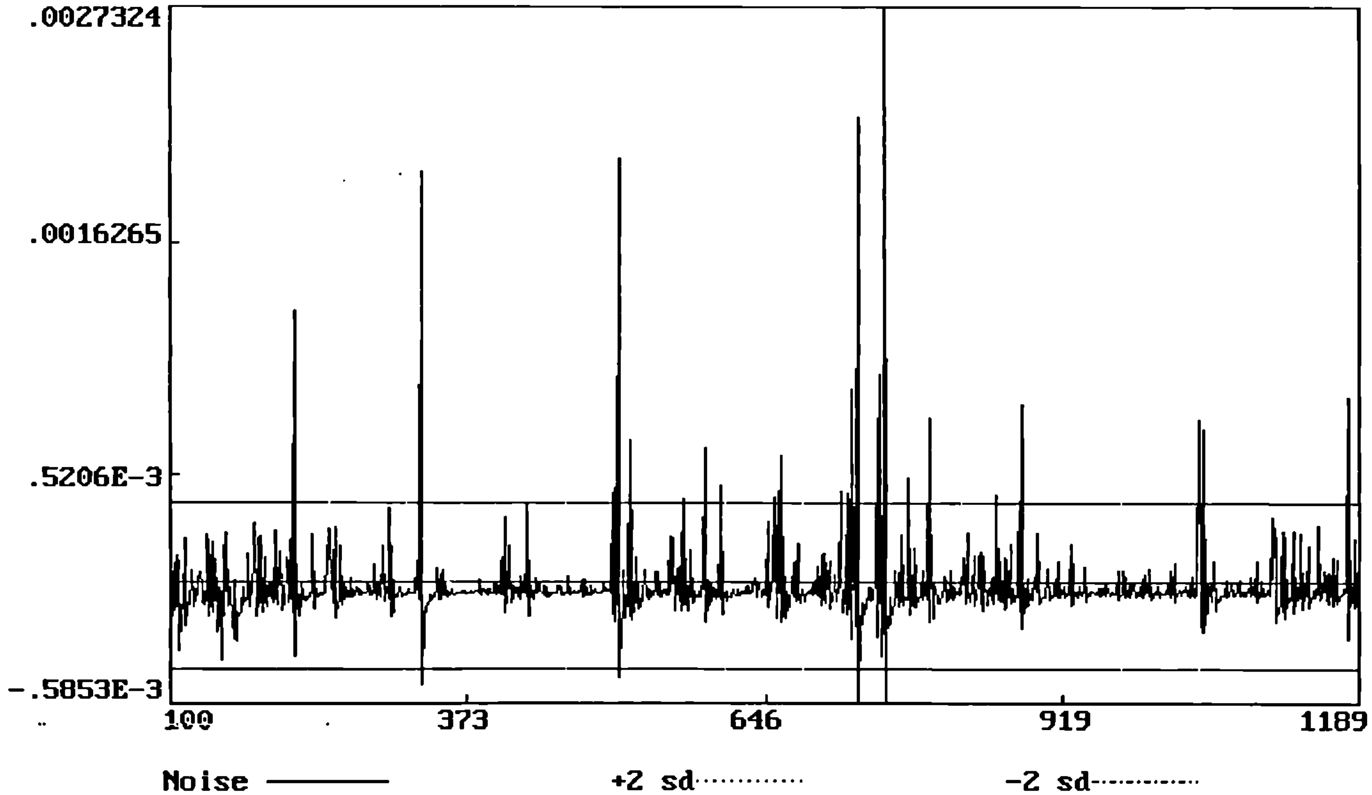
GARCH Model Test Statistics (Daily)

Test	Brent Spot	
	Pre-futures	Post-futures
Heteroskedasticity		
Lag 1	0.98	1.26
2	1.34	1.39
3	1.85	1.49
4	5.67	1.49
Autocorrelation		
Lag 1	1.36	0.10
2	1.87	0.27
3	1.93	0.99
4	2.96	1.27
Integration	-6.80	-3.90

Tests for heteroskedasticity and autocorrelation are Ljung-Box statistics and are χ^2 distributed. Critical values at 5% are 3.84, 5.99, 7.81, and 9.49 for lags of 1, 2, 3, and 4 respectively. Test for integration is an ADF test with a critical value at 5% = -2.86.

Figure 2.4

Noise with 2 Standard Deviation Bounds



2.7 Summary and Conclusions

The goal of this chapter was to examine the effects of the introduction of futures trading on the price volatility of the Brent crude spot oil market, adopting the recently developed GARCH time series techniques, and the Kalman filter. The data set consisted of both daily and weekly data from January 1986 to July 1990 for Brent crude oil.

Preliminary investigations employing a dynamic linear regression model for weekly data provided results comparable to previous studies and also served to highlight the appropriateness of the GARCH process in the study of volatility. Results from the regression analysis are consistent with the majority of similar previous studies in that they reveal no apparent change in volatility. The documented tendency for returns time series for speculative markets to show volatility clustering appears to be the case for Brent crude oil (see Figures 2.1 to 2.3). Such observations seriously question the validity of linear regression models constructed under the assumption of homoskedasticity of the variance. It is for this reason that GARCH, which allows for time-varying variance in a process, is more appropriate to an analysis of volatility.

Results from the weekly GARCH models reveal that while the pre-futures sample was integrated, suggesting that shocks have a permanent effect on prices, the post-futures sample was stationary; for daily data both periods were stationary. For weekly data, this implies that the introduction of futures markets improves the quality of information flowing to spot markets, and that spot prices accordingly reflect more promptly changes that occur in demand and supply conditions. The integratedness of the pre-futures market illustrates the lack of information and associated price inflexibility in the spot market. Such inflexibility prevents the immediate and continuing adjustment of prices in response to demand-supply conditions and necessitates eventual larger price and resource adjustments. In addition both models suggest that the overall magnitude of volatility has not undergone significant change, but that the nature of volatility has been significantly transformed.

For the weekly data series the increase in volatility due to the "news" coefficient shows the market to have a greater response to news information. It is reasonable to assume that the identification of, and reaction to news information has increased since futures trading began. Similarly the drop in short-term persistence of volatility supports this conclusion since it shows that news is impounded into prices more quickly, and that the rate at which the market is able to update news has increased; the market has become better able at using information. Moreover, this could indicate increased pricing efficiency in the spot market as agents use near-term futures prices to help set spot and forward prices.

Thus, increased volatility in terms of the α_1 news term in the GARCH model, (equation 2.24) may simply be the manifestation of the market functioning more efficiently. The change in integration also attests to the efficiency improvements brought since the onset of futures trading. These results are consistent both with the notion that futures markets have a price discovery function, and with the theoretical arguments put forward by Ross (1989), which suggest that price volatility increases as the rate of information flow increases. Finally, the decrease in the coefficient on the lagged conditional variance (i.e. the GARCH-M component, δ in equation 2.23), attests to the view that with the introduction of futures contracts spot market volatility is not as important to spot market participants since price risk can now be hedged.

For the daily data we also observe a change in the nature of volatility. In this case, however, the market appears to be less efficient, with traders reacting less to news and more to previous price movements; the opposite result to that discussed above for weekly data. We explain these results by suggesting that on a daily basis the spot market is acting less efficiently in the presence of a futures market, and that the greater divergence from fundamentals is due to noise trading brought, presumably, by the increased speculation in the oil market. Daily persistence is, however, stationary in the post-futures period suggesting that while there has been an increase in the effect of past information on price returns it is not so great as to cause prices to behave as an integrated process.

The question of the overall effect of futures trading must take account of what may initially be seen as contradictory evidence from both the weekly and daily data. The spot market appears to have become more efficient on a weekly basis, with the efficiency gains being generated by the actions of speculators brought by the futures markets. At some level, however, markets will face inefficiencies and in the case of the oil market this level is reached on a daily basis. Here the inflow of speculative trading has led to inefficiencies due to increased noise trading. Ironically, it is this speculation which supports the efficiency improvements on a weekly level as the short-run noise effects do not persist, but information improvements emerge.

An explanation for the observed results could be that futures markets attract informed speculators away from the spot market leading to a relative reduction in the physical market's efficiency. On a weekly basis, however, the information improvements associated with futures markets could feed back into the spot market, improving its price responsiveness to information.

In conclusion this study finds no decisive evidence to suggest that there has been a spillover of volatility from the futures to the spot market. Rather the results imply that futures markets serve their prescribed role of improving pricing efficiency. The most apparent policy implication of these results is that while the increased regulation of futures markets may reduce volatility, they may be doing so by inducing what Edwards (1988a) terms 'deficient' volatility, where prices fail to attain the level dictated by fundamentals. The resultant mispricing has social costs which are much more obvious than the costs attributed to the excessive volatility caused by futures trading. The most obvious question arising from the volatility debate is whether spot market volatility *is* excessive in the presence of futures markets.

It is difficult to quantify (or even identify) excessive volatility however, and while comparisons of volatility patterns with and without futures may indicate a change in volatility, one may question the reliability of the benchmark. If volatility increases post-futures, and that volatility is due to improved pricing signals, then the argument against futures trading is stood on its head. If the pre-futures spot price was inefficient, and exhibited deficient volatility as a consequence, then the increased volatility post-futures should be welcomed rather than treated with suspicion.

It should not then be particularly surprising if futures trading leads to short-term volatility since, as Brorsen (1991) suggests, any innovation which reduces market frictions will both increase market efficiency and increase the variance of short-run price changes. The effect of increased regulation of futures markets through increased margin requirements or higher transactions costs merely reintroduces those frictions removed by liberal futures trading, reducing short-run volatility but also removing the benefits of futures. As proposed *inter alia* by Figlewski (1981) and Brorsen *et al* (1989), the costs of short-run volatility can be acceptable in light of the benefits afforded by futures.

There may in fact be benefits from the volatility induced by futures trading, particularly where the pre-futures spot market was subject to monopolistic pricing. Here the introduction of an alternative instrument for the purchase and sale of a commodity at competitive prices will push prices towards fundamentals. Given the close links between spot and futures prices this competitive pressure should also find its way to the spot market. This point is particularly relevant to the Brent spot market which is largely controlled by a small number of oil companies, and so open to monopolistic pricing in the absence of an alternative trading arena.

Given that futures markets face lower transactions costs than spot markets one can expect them to experience fewer frictions and so react more quickly information. Spot and futures prices will, however, move closely together due to the arbitrage forces operating between them. When one further considers the contemporaneous price discovery function of futures markets (see Chapter 4) it becomes apparent that a spot market's reactions to information will become quicker in the presence of an active futures market as the future's price response permeates into the spot market. This observation can explain the finding that spot markets were integrated before the inception of futures trading and not thereafter.

The results of this investigation differ from the majority of previous studies in that it addresses not only the question of whether the magnitude of volatility has changed since the advent of futures trading, but also asks whether the characteristics of that volatility have changed. In so doing this study focuses on the link between volatility, information flow and efficiency. Findings suggest that increased volatility can have positive connotations, and that attempts to regulate futures markets must be carefully considered.

CHAPTER 3*

SHORT-TERM AND LONG-TERM EFFICIENCY IN OIL FUTURES MARKETS.

3.1 INTRODUCTION

The international oil market, as much as any other commodity market, has had its share of price uncertainty. The frequently recalled price shocks of 1973/4 and 1979 were not the oil market's first experiences of sudden price shifts, but their notoriety endures.[33] Other notable events in the international market for oil include the price collapse in 1986 and the Gulf Crisis of 1990/91. More recently, albeit on a much smaller scale, has been the uncertainty surrounding the lifting of UN sanctions on Iraqi oil exports, and the return of its production to the market.

The presence of price uncertainty in commodity markets prompts agents within those markets to seek shelter against the risk which uncertain future price movements implies. This risk has real economic consequences; first it can reduce both production and consumption and so lead to welfare losses, and second it can lead agents to incur additional costs in seeking out information not already impounded in prices. Futures trading is initiated in response to these perceived risks, and agents' demands for a vehicle to ameliorate their negative effects.

* The main elements of this Chapter have appeared in Antoniou and Foster (1993a).

[33] The discovery of oil in East Texas in 1930 saw oil prices plummet from $1 a barrel to 6¢. Similarly an oil glut saw prices fall from $20 per barrel in 1960 to 20¢ per barrel in 1961. The oil industry has also experienced price uncertainty with the nationalisation of BP's Iranian holdings in 1951 and the blockage of the Suez canal in 1956.

An issue central to the analysis of futures markets is whether a futures price coincides with the expected future spot price for the date when the futures contract matures. The issue is not fully resolved in the literature. One view holds that expected spot prices and current futures price are not equal, and their difference is explained by the presence of a risk premium which accrues to speculators. Keynes (1930) and Hicks (1946) attribute such bias to hedging pressures where the supply of futures contracts by hedgers wishing to protect themselves against price risk drives down futures prices to the point where they offer a risk premium over the expected future spot price sufficient to compensate speculators for assuming risk. The resulting risk premium generates the observes normal backwardation in futures prices.

The alternative view is that speculation acts to assure that the current futures price is equal to the expected future spot price and in this sense acts as an unbiased predictor of that spot price. As noted by Purcell (1991), futures markets are, by definition, anticipatory pricing markets and as such the price of a futures contract can be interpreted as the market's consensus as to what the (spot) price will be in the future. It is through their ascribed role of providing unbiased predictions of future spot prices that futures contracts are viewed as offering a vehicle for reducing or eliminating the risk due to price fluctuations. If agents are to make decisions based on futures prices then the effectiveness of futures in this ascribed role is of primary concern.

The effectiveness of futures markets in providing this service is dependent upon their own efficiency. If futures markets are inefficient in the sense that they do not incorporate all relevant information and are, therefore, biased predictors of future spot prices they will not only fail to reduce agents' risks but will introduce extra costs, thereby aggravating the initial conditions of uncertainty and promoting resource misallocation. Thus, the existence of futures markets does not necessarily guarantee that welfare losses from price uncertainty will be eliminated, and they may bring with them extra costs. Tests of futures market efficiency are thus necessitated.

This chapter presents tests of efficiency by investigating the ability of futures prices for Brent and WTI crude oils to act as unbiased predictors of their respective future spot prices. To this end the analysis uses cointegration, and examines the underlying error-correction models (ECMs). The objective here is to extend long-term (cointegration) tests of efficiency by employing ECMs in order to test for efficiency in the short-term. Within this framework it is demonstrated that while a market may be deemed long-term efficient, there may be short-term inefficiencies within that long-term equilibrium relationship.

Tests of efficiency in futures markets have typically been based on the confirmation of two assumptions; that agents are risk neutral, and that they make rational use of all available information. These elements constitute the joint assumptions underlying practical tests of futures market efficiency. Under conditions where there is no risk premium (implying risk neutral market participants), and where the absence of unexploited profit opportunities confirms the rational and efficient use of information, the market may be described as being efficient. Confirmation of these assumptions suggests that the current futures price serves as an unbiased predictor of the future spot price. Acceptance of the joint hypothesis that both assumptions hold implies that futures markets demonstrate pricing efficiency. In contrast, rejection of the hypothesis may suggest pricing inefficiency, the presence of a risk premium, or both. Due to the nature of the joint hypotheses isolation of the precise cause of rejection very difficult.

Testing efficiency within the framework of cointegration is based on Granger's (1986) assertion that spot and futures market prices should not diverge from one another to too great an extent, at least in the long-term. Following Granger one may intimate that the efficiency of futures markets is demonstrated when spot and futures prices have a confluent evolution, i.e. they must be cointegrated. Cointegration alone, however, is only a necessary condition for efficiency; spot and futures prices drifting apart in the short-term would be consistent with a long-term cointegrating relationship. This situation commands an analysis of the ECM underlying the cointegration regression, in order that short-term dynamics can be examined.

This chapter investigates futures market efficiency by testing for cointegration between spot and futures prices for various contract maturities, and by analysing their ECMs. In brief, the findings of this chapter are that the WTI futures market is efficient in the long-term for at least three months from maturity, while the Brent market is cointegrated for one and two months only, but long-term inefficient for those maturities. In the short-term both the WTI and the Brent futures market is found to be inefficient over all contract maturities considered. The size and maturity of the WTI futures market are forwarded as key explanations for its greater long-term efficiency relative to the Brent market.

The chapter proceeds as follows. Section 3.2 presents a discussion of the theoretical issues of market efficiency in the context of futures markets. Section 3.3 presents both intuitive and formal definitions of cointegration, while Section 3.4 describes its application to tests of efficiency. Section 3.5 describes the data used in the empirical investigation and presents some preliminary results. Empirical results for tests of futures efficiency are presented and discussed in Section 3.6, with Section 3.7 providing concluding remarks to the chapter.

3.2 ISSUES OF MARKET EFFICIENCY

The generally accepted notion of an efficient market, as prescribed by the Efficient Markets Hypothesis (EMH), see Fama (1970), is one in which prices fully and instantaneously reflect all available, relevant information. If prices do react quickly and correctly to the arrival of new information, then they will provide accurate signals for resource allocation. Earlier definitions of market efficiency have been subject to much criticism and a degree of misinterpretation. What the EMH does not say is that prices will reflect *all* information; this distinction allowing the coexistence of efficient pricing with unreflected relevant information whose marginal cost of detection and use outweighs its benefits, or whose addition to the current information set would be trivial. This view is supported by Fama (1991):

> "A weaker and more sensible version of the efficiency hypothesis says that prices reflect information to the point where the marginal benefits of

acting on information do not exceed the marginal costs" [1991, p.1575]

Furthermore, it is suggested by Beaver (1989) that the original statements on efficiency were not intended to provide rigorous definitions, rather they offered an intuitive description of the concept of efficiency. From this point the notion of efficiency has been clarified by focusing on its main implication: the 'fair game' property, whereby a market is efficient with respect to a given information set if agents play a fair game with respect to that information. The presence of a fair game implies that agents will expect abnormal returns from active trading based on the information set to be zero. Within this framework one may define the current information set, Ω_t, which reflects all available, relevant information discovered to date. Irrelevant, private and trivial information may still exist, but they lie beyond the boundaries of Ω_t and so will not influence current prices.

In the context of futures markets, efficiency is indicated by establishing the absence of predictable arbitrage opportunities between the futures market and its spot market; this effectively represents a test of the futures price offering agents a fair game with respect to Ω_t, in that the futures market is characterised by a martingale process. This is illustrated in equation (3.1) which implies that the expected spot price at the time the current futures contract matures is equal to the current futures price.[34]

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[34]Since S_{t+n} and $F_{t+n,t+n}$ will be equivalent, equation 3.1 can be reexpressed as a familiar martingale process:

$$E[F_{t+n,t+n} - F_{t,t+n} \mid \Omega_t] = 0$$

$$E[S_{t+n} - F_{t,t+n} | \Omega_t] = 0 \qquad (3.1)$$

where $E[S_{t+n}]$ is the expected future spot price n periods ahead
$F_{t,t+n}$ is the current futures price which matures at t+n.
Ω_t is the current information set

Thus, from equation (3.1) it can be seen that the expected profit from entering into a futures position is zero. Furthermore, rational expectations imply that the expected future spot price will equal the realised future spot price, that is:

$$S_{t+n} = E[S_{t+n} \mid \Omega_t] + \epsilon_{t+n} \qquad (3.2)$$

where $E[\varepsilon_{t+n} \mid \Omega_t] = 0$

Equations (3.1) and (3.2) together imply that the future spot price may be represented as:

$$F_{t,t+n} = E[S_{t+n} | \Omega_t] \qquad (3.3)$$

As outlined in Section 3.1, if both elements of the joint hypothesis of risk neutrality and rational use of information are attained, then the futures price will serve as an unbiased predictor of the future spot price i.e. the current price of a futures contract which matures at a specific date in the future will represent the market's expectation of the realised spot price at that future date. It is exactly this relationship which is represented in equation (3.3) above, and which forms the basis of tests of efficiency used here.

Due to the arrival and impounding of new information between the periods t and t+n, the realised spot price, S_{t+n}, will naturally differ from its (rational) expectation conditional on Ω_t. The price adjustment due to new information may be represented as a forecast error, the inclusion of which allows equation (3.3) to be operationalised as follows;

$$S_{t+n} = F_{t,t+n} + \epsilon_t \tag{3.4a}$$

Conventionally efficiency is tested by regressing (log) spot price at maturity on (log) futures price at a given period prior to maturity, and a forecast error. In addition an intercept term is included which represents the risk premia:

$$S_{t+n} = \alpha + \beta F_{t,t+n} + \epsilon_t \tag{3.4b}$$

Market efficiency is confirmed when the joint restriction $\alpha=0$, and $\beta=1$ holds. This restriction has been tested using standard regression analysis, see Geweke and Feige (1979), Hansen and Hodrick (1980), and Huang (1984). The use of OLS in testing these restrictions is, however, inappropriate since the assumptions upon which OLS are based are violated when non-stationary data are used, namely that the asymptotic distribution theory upon which hypothesis tests are based requires stationarity.[35] The resulting unreliability of test statistics in the presence of non-stationary data leads to inferences made from such regressions being invalid. The inappropriateness of OLS derives from the fact that the standard F-test of the null hypothesis $\alpha=0$, $\delta=1$ is biased towards Type I errors; falsely rejecting the null of efficiency. This point was demonstrated using Monte Carlo experiments by Elam and Dixon (1988). The effects

[35] Spot and futures prices are commonly nonstationary in levels. This observation is confirmed for the data series used in this study, see Section 3.5 and Table 3.1.

of this have been commented upon *inter alia* by Barnhart and Szakmary:

> "If the series under investigation are nonstationary, the usual distributional results and tests of significance are no longer valid ... (and) statistical inference about the estimated parameters can be very misleading." [1991, p.248]

A solution is offered by cointegration which deals specifically with relationships between nonstationary series. Thus, given the problems outlined above it is desirable to adopt cointegration as a more appropriate methodology for testing efficiency. A number of recent investigations into efficiency have already adopted cointegration, see Hakkio and Rush (1989), Lai and Lai (1991), and Barnhart and Szakmary (1991). A further important consideration, however, is that cointegration tests only whether markets are efficient in the long-term and ignores short-term considerations. As such an error-correction model, which incorporates short-term dynamics, should be specified for market efficiency to be adequately tested. The next section provides intuitive and theoretical explanations of cointegration and ECMs. The application of these techniques to tests of efficiency are dealt with in Section 3.4.

3.3 COINTEGRATION

The Concept of Cointegration

Before proceeding to a technical discussion of cointegration and how it relates to efficiency, it will be beneficial to present an intuitive explanation of this technique.

Cointegration is a technique which allows the analysis of long-run equilibrium relationships based on the premise that while many economic variables exhibit non-stationary behaviour in the short-run, they may drift together in the long-run. If variables do exhibit such long-run linear relationships then cointegration offers a way of detecting and analysing that affinity. As such cointegration allows the testing of economic theories which suggest that certain variables should be related even though they exhibit mutually stochastic behaviour. In short, cointegration theory allows the reconciliation of observed short-term dynamic behaviour with an expected long-term equilibrium. Granger (1986) reported the spot and futures prices of a commodity to be examples of economic variables which may drift apart in the short-run, but should not diverge by too great an extent in the long-run. This point is elaborated by Engle and Granger (1987) who state that given a long-run equilibrium between time series,

> ". . . cointegration implies that deviations from equilibrium are stationary, with finite variance, even though the series themselves are nonstationary and have infinite variance." [1987, p.251]

The underlying concept here is that the (theoretically) infinite variances of the cointegrating series will offset each other such that the linear combination of those series has a finite variance. In this regard the notion that two series will not 'drift apart' is given a more precise definition; that their difference is stationary. It is this stationarity which characterises the long-run equilibrium relationship. In the following a formal description of cointegration is presented and its relation to tests of efficiency described.

Cointegration and Efficiency

As mentioned in Section 3.2 most observed speculative price series appear to violate the stationarity assumption upon which the bulk of classical statistical theory is based. Granger and Newbold (1974) demonstrate that OLS regressions estimated in the presence of non-stationary variables could produce unreliable *t*-statistics which may lead to the acceptance of relationships which are 'spurious.' As a result the use of differenced data in econometric analysis is commonly recommended if stationarity is to be assumed to hold. It is the necessity to difference data - or rather the lack of such a necessity - which lies at the heart of cointegration.

In circumstances where a series achieves stationarity after first differencing that series is said to be integrated of order one, denoted I(1). In general, a series such as a spot price, S_t, which is nonstationary in levels but achieves stationarity after being differenced d times is represented as $S_t \sim I(d)$. An I(0) series is said to be levels stationary. Here stationarity is taken to be *weak* stationarity, that is where a weakly stationary series has constant first and second moments.

When two series such as a spot price S_{t+n}, and a futures price $F_{t,t+n}$ are integrated of order d in levels then a linear combination Z_t can also be integrated of order d.

$$Z_t = S_{t+n} - \alpha - \delta F_{t,t+n} \qquad Z_t \sim I(d) \qquad (3.5a)$$

Engle and Granger (1987) note, however, that it is possible for a linear combination of two I(d) series to be integrated of an order lower than d. In such circumstances the variables are said to cointegrate. Of particular interest is the special case where a combination of two nonstationary series is stationary in levels, indicating some long-run or equilibrium relationship between the cointegrating series. Stationarity is implied when the residuals of the cointegrating regression are I(0), and is established by testing for and rejecting a null hypothesis of a unit root (nonstationarity) in the residuals. Rejection of the null hypothesis of nonstationarity suggests that the cointegrating series will not 'drift apart' in the long-run. For the purpose of testing the relationship in (3.5a) is represented as:[36]

$$S_{t+n} = \alpha + \delta F_{t,t+n} + \epsilon_t \qquad (3.5b)$$

A *necessary* condition for futures market efficiency is that the spot and futures series in equation (3.5b) are cointegrated in that the residuals from that cointegrating regression are I(0). Should they fail to cointegrate with stationary errors then the futures price and future spot price will drift apart indefinitely, precluding the former from being an unbiased predictor of the latter. It is this observation which invites the use of cointegration in testing futures markets' efficiency. A detailed explanation of the use of cointegration in testing unbiasedness is provided in Section 3.4.

Cointegration and Error-correction Models

The relationship between cointegration and ECMs was first noted by Granger (1981), with a formal theory demonstrating how cointegrated series can be represented by an ECM given in Granger (1983). The resulting Granger Representation Theorem, Granger (1983), Engle and Granger (1987), establishes that if there exists a

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[36] The cointegrating regression in equation (3.5b) is equivalent to the levels specification in equation (3.4b).

cointegrating relationship between two I(1) series then there will be an underlying ECM characterising that relationship. In fact, it is the ECM which affords cointegration theory its aforementioned ability to reconcile a long-run equilibrium with short-run dynamics. Engle and Granger (1987) demonstrate that under conditions of cointegration it can be shown that;

> "... a class of models, known as error-correcting, allows long-run components of variables to obey equilibrium constraints while short-run components have a dynamic specification." [1987, p.252]

Thus, where two variables such as S_{t+n} and $F_{t,t+n}$ cointegrate, then the following ECM can be specified;[37]

$$\Delta S_{t+n} = \alpha + \sum_{i=0}^{k} \gamma_i \Delta F_{t,t+n-i} + \sum_{j=1}^{l} \phi_j \Delta S_{t+n-j} + \rho\left[S_{t+n-1} - \delta F_{t-1,t+n}\right] + \epsilon_{t+n} \quad (3.6)$$

where $[S_{t+n-1} - \delta F_{t-1,t+n}]$ is the error-correction term.

Equation (3.6) represents the standard ECM which contains only stationary variables thus permitting the use of standard regression techniques.[38] The practical implication of this is that the spurious regression problem is removed.

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[37] Under rational expectations if n>1 then the error term, ε_{t+n}, is a moving-average process of order MA(n-1).

[38] Since S_{t+n} and $F_{t,t+n}$ cointegrate the error-correction term defined by their difference will be stationary.

Johansen's Multivariate Cointegration

The majority of studies investigating efficiency using cointegration have adopted the Engle and Granger two-step cointegration procedure, where one variable is regressed on the other, and then the residuals from that regression are tested for the presence of a unit root. This approach, however, has two inherent problems; that the cointegrating vector is assumed to be unique,[39] and that the test procedure does not have well defined limiting distributions. It follows from the latter limitation that Engle and Granger cointegration cannot encompass the reliable testing of restrictions on the cointegrating regression's parameters; in this case the restrictions $\alpha=0$ and $\delta=1$ required for efficiency.

Solutions to these problems are offered by Johansen's multivariate approach (Johansen (1988), Johansen and Juselius (1990)). Unlike the Engle and Granger cointegration procedure which uses standard regression analysis, the Johansen approach is based on maximum likelihood (ML) estimation; deriving ML estimators of the cointegrating vectors and using likelihood ratio (LR) tests for hypothesis testing.

The Johansen technique tests the null hypothesis of there being no cointegrating vectors against the alternative hypothesis that there is one (or more) cointegrating vector(s), thus permitting the identification of all the distinct cointegrating vectors between a set of variables. In addition, Johansen's procedure allows for the

[39] This does not present a particular problem in this study because the number of cointegrating variables, N, considered here is two. Since there can be up to N-1 cointegrating vectors, the vector must be unique. Naturally, where N>2 the uniqueness of the cointegrating vector cannot be guaranteed using Engle and Granger cointegration.

construction of likelihood ratio tests on restrictions on the parameters of the cointegrating regression. The following presents an outline of the Johansen procedure, beginning with the estimation of the numbers of cointegrating vectors and then illustrating how hypothesis testing on those vectors is undertaken.

Johansen's analysis begins by defining a general vector autoregression (VAR) process in levels,

$$X_t = \mu + \sum_{i=1}^{k} \Pi_i X_{t-i} + \epsilon_t \tag{3.7}$$

where X_t is an N x 1 column vector of the I(1) variables under consideration, in this case $X_t' = (S_{t+n}\ F_{t,t+n})$
Π_i is an N x N matrix of parameters
μ is a vector of constants
ε_t is an i.i.d. vector of mean-zero errors with covariance matrix Λ; $\varepsilon_t \sim N(0,\Lambda)$

The cointegrating matrix, Π, contains the information necessary to ascertain the number of cointegrating between the variables in X_t. This is an N×N matrix and is defined as,

$$\Pi = I - \Pi_1 - \Pi_2 - \dots - \Pi_k$$

where I is the identity matrix.

Johansen and Juselius (1990) suggest that an examination of the cointegrating matrix be undertaken by reparameterising equation (3.7) to give its equivalent error-correction representation as below,

$$\Delta X_t = \mu + \sum_{i=1}^{k-1} \Gamma_i \Delta X_{t-i} + \Pi X_{t-k} + \epsilon_t \tag{3.8}$$

where $\Gamma_i = -I + \Pi_1 + \Pi_2 + \dots + \Pi_i \qquad (i=1, \dots, k-1)$

Since the vector X_t contains I(1) variables it is evident that the first-differenced terms in equation (3.8) i.e. the LHS term (ΔX_t), and the first k-1 terms on the RHS ($\Gamma_i \Delta X_{t-i}$), are I(0). Equation (3.8) differs from the standard first-difference form of equation (3.7) only in terms of the final RHS term, ΠX_{t-k}. Again it is this term, Π, which is of interest in testing for cointegration since it represents the stationary linear combination of I(1) variables.

As alluded to above, information about the long-run cointegrating relationship between the variables in X_t is found through an examination of the matrix Π. Under the Johansen procedure the hypothesis of cointegration is fashioned as the hypothesis of reduced rank of Π. Where Π has full rank (or where its rank is zero) cointegration will not be present, in the contrary case cointegration is attained. Specifically, the maximum number of linearly independent rows in Π i.e. its rank, corresponds to the number of distinct cointegrating vectors, **r**, which exist between the variables in X_t. Where such a vector contains N variables, each of order I(1), there can feasibly be up to N-1 distinct cointegrating vectors. The three possible forms which Π can take are summarised by Johansen and Juselius (1990) as follows, with the original notation changed for the purpose of consistent presentation.

(i) Rank(Π) = N. i.e. the matrix Π has full rank, indicating that the vector process X_t is stationary.

(ii) Rank(Π) = 0. i.e. the matrix Π is the null matrix .

(iii) $0 < \text{rank}(\Pi) = \mathbf{r} < N$ implying that there are two Nxr matrices α and β such that $\Pi = \alpha\beta'$ [1990, p.170]

In this investigation X_t is a 2×1 vector of I(1) variables, and as such the rank of Π can be either 1 or zero indicating cointegration and non-cointegration respectively. The implied $N \times \mathbf{r}$ matrices α and β are presented in equation (3.9).

$$\Pi = \alpha\beta' \tag{3.9}$$

The rows of β form the **r** distinct cointegrating vectors, while α is the matrix of adjustment coefficients. Equation (3.9) forms the main hypothesis to be tested in the Johansen procedure, it forms the hypothesis that there are (at most) **r** cointegrating vectors. Acceptance of the hypothesis implies that even though X_t is nonstationary, the linear combination $\beta'X_t$ is levels stationary; this stationary relationship amongst nonstationary variables being interpreted as the cointegrating relationship.

Johansen (1991) states that the parameters of α and β cannot be identified, but notes that it is possible to determine the space spanned by them. The space spanned by β, the cointegrating space, is the row space of Π, while the space spanned by α (the adjustment space) is the column space of Π.

As demonstrated by Johansen and Juselius (1990) in their Theorem 4.1, β is estimated as the eigenvector associated with the **r** largest statistically significant eigenvalues found by solving the equation,

$$| \lambda S_{kk} - S_{k0} S_{00}^{-1} S_{0k} | = 0 \tag{3.10}$$

where S_{kk} is the residual moment matrix from an OLS regression of X_{t-k} on ΔX_{t-k+1}
S_{00} is the residual moment matrix from regressing ΔX_t on $\Delta X_{t-1}, \ldots, \Delta X_{t-k+1}$
S_{0k} is the cross-product moment matrix

Solving equation (3.10) yields the eigenvalues $\lambda_1 > \ldots > \lambda_N$ which are used to test the hypothesis of there being at most **r** cointegrating vectors using the LR test

$$LR = -2\ln(Q) = -T\sum_{i=r+1}^{N} \ln(1-\lambda_i) \tag{3.11}$$

where T denotes the number of observations and Q = restricted ML/unrestricted ML. The methodology for extracting the eigenvalues is given full treatment in Johansen (1988).

As mentioned previously, in addition to detecting cointegrating vectors, the Johansen procedure shows how restrictions on the parameters of the cointegrating vectors can be tested. In the following this procedure is described with reference to the restrictions pertinent to tests of efficiency. The ensuing illustration borrows from the intuitive exposition provided by Lai and Lai (1991, p570). Returning to the definition of the stationary linear combination of nonstationary variables $\beta' X_t$, we may define,

$$\beta' X_t^* = 0 \tag{3.12}$$

where $X_t^* = (S_{t+n}, F_{t,t+n}, 1)$
$\beta' = (1, -\delta, -\alpha)$

Solving equation (3.12) gives the cointegrating regression in equation (3.5b):

$$\begin{bmatrix} 1 \\ -\delta \\ -\alpha \end{bmatrix} [S_{t+n}\ F_{t,t+n}\ 1] = 0$$

$$S_{t+n} - \delta F_{t,t+n} - \alpha = 0$$

$$S_{t+n} = \alpha + \delta F_{t,t+n} \tag{3.5b}$$

The testing of efficiency is thus constructed by testing the linear restrictions imposed when $\beta' = (1, -1, 0)$, which normalises $S_{t,t+n}$ to be unity and yields the restrictions $\alpha=0$, $\delta=1$. It is recalled that these are the necessary conditions for efficiency required in equation (3.5b). The restrictions on β can be presented as the hypothesis,

$$H0\text{: } \beta = G\phi \tag{3.13}$$

where G is an 3×m matrix of full rank m
ϕ is an m×r matrix of parameters ($3 \geq m \geq r$)

The condition necessary for efficiency is described as G = (1, -1, 0). Since G is a 3×1 vector and there can be up to one equilibrium relationship (r = 1), ϕ is a scalar. The LR test for the above hypothesis is given as,

$$-2\ln(Q) = -T\sum_{i=1}^{r} \ln((1-\lambda_i)/(1-\lambda_i^*)) \tag{3.14}$$

where λ_i^* are the eigenvalues for the restricted model. The test has an asymptotic χ^2 distribution with degrees of freedom equal to the number of restrictions being tested.

3.4 Tests of Futures Market Efficiency

Long-run Efficiency and Cointegration

In this investigation we specify three main conditions and one ancillary condition for testing the unbiasedness and efficiency of futures markets. The first two conditions are necessary, whilst the third condition is sufficient. These are explained in detail below and summarised thereafter. In examining the efficiency between spot and futures price series, the first necessary condition for efficiency is that the series are cointegrated, that is, the residuals from the cointegrating regression are stationary. Cointegration is necessary for efficiency since its absence would indicate that the two series will drift apart, implying that the futures price no longer acts as an unbiased predictor of the spot price. As shown by Hakkio and Rush (1989), cointegration is, however, only a necessary and not sufficient condition for market efficiency. Tests of market efficiency also require that the cointegrating vector is a unit vector[40] and that risk neutrality is present. If either or both of the above restrictions do not hold then the futures price cannot be an unbiased predictor of the future spot price. The testing of these restrictions constitutes the second necessary condition for futures market efficiency.

Short-run Efficiency and the ECM

While a unit cointegrating vector (given risk neutrality) suggests that, in the long-term, the futures price is an unbiased predictor of the future spot price, in the short-term there could be substantial egressions from this relationship. Under these circumstances an ECM should be used to test this dynamic relationship. Since the specification of the ECM and cointegration model are equivalent, efficiency can be tested by imposing the following restrictions on the ECM in equation (3.6); $-\rho=\gamma=\delta=1$, and all lagged values, ϕ, are zero. To illustrate, equation (3.6) is rewritten as:

[40] A unit vector is defined here as a vector consisting entirely of elements equal to 1.

$$\Delta S_{t+n} = \gamma F_{t,t+n} - \gamma F_{t-1,t+n} + \phi \Delta S_{t+n-1} + \rho S_{t+n-1} - \rho \delta F_{t-1,t+n} \tag{3.15}$$

If lagged values, ϕ, are zero, and the restriction δ=1 is imposed, then the above can be reexpressed as:

$$S_{t+n} - S_{t+n-1} = \gamma F_{t,t+n} - \gamma F_{t-1,t+n} + \rho S_{t+n-1} - \rho F_{t-1,t+n} \tag{3.16}$$

Finally, imposing the restriction $-\rho=\gamma=1$ and simplifying yields the equilibrium relationship:

$$S_{t+n} = F_{t,t+n} \tag{3.17}$$

These restrictions form the third condition in testing for efficiency. Furthermore, we may add to these conditions the requirement that the coefficients of the error-correction model are stable over time, thus ensuring that the results generated are not sensitive to the sample period used.

To summarise, the conditions for testing futures market efficiency are as follows.

1. The spot and futures price series must cointegrate.
2. In the cointegrating regression the intercept is zero and the cointegrating vector is a unit vector, i.e. α=0 and δ=1 in equation (3.5b).
3. In the ECM, equation (3.6), the coefficients on futures returns and the error-correction term should be equal to one, i.e. $-\rho=\gamma=1$, and the coefficients on any lagged spot returns should be zero, ϕ=0.

3.5 Data and Preliminary Results

The data set used in this investigation consists of monthly spot and futures prices for UK Brent crude oil and US WTI crude oil.[41] The UK data has a sample period from the July contract 1989[42] to the December contract 1993, representing 54 monthly observations. The sample period for US data is from the September contract 1983 to the December contract 1993, representing 124 monthly observations. Futures contracts on the oil markets are traded for delivery in every month of the year.

Due to the expectation that the information set (Ω_t in equation 3.3) will be updated as the futures contract moves closer to maturity, nearby futures contracts should provide better estimates of the future spot price than those further away from maturity. This expectation is analysed here by testing the unbiasedness hypothesis over a number of maturities. Futures price observations for each oil commodity are thus grouped according to their time to maturity; the first group consisting of futures prices one month before the maturity month i.e. the nearby contract. Two other maturity groups representing two and three months from the maturity month were also constructed. These three contracts together account for over ninety percent of trading activity.

The IPE Brent Crude futures contract ceases trading on the business day preceding the 15th day of the month before the delivery month. If that day is a non-business day,

[41] The last daily price of the month is used as the monthly observation.

[42] This is the earliest contract for which sufficient data is available to construct futures series up to 3 months from maturity.

then trading ceases on the first business day prior to that day. Similarly, the NYMEX WTI Crude contract ceases trading three business days prior to the 25th calendar day of the month preceding the delivery month. Given the resulting distinction between the maturity months and the delivery months care must be taken in constructing the futures price series. To this end the one-month (nearby) futures price is taken to be the price quoted during the month prior to the month in which the contract matures, rather then the month in which delivery is due. The corresponding spot price is taken for the 'maturity' month. For example, when constructing the one-month futures price series, the futures price for the contract deliverable in March 1993, but maturing in February 1993, is taken as the price in January 1993, with the corresponding spot price taken from February 1993. The two and three-month contract series are constructed in an analogous fashion.

Tests for Unit Roots

Unit root tests were carried out on the spot series and the three futures series for each oil commodity. Johansen's cointegration procedure was used to test for the presence unit roots (nonstationarity) in levels spot and futures price series. This is achieved by testing for cointegration in one variable, i.e. testing for integration. All series accept the null of no cointegration in levels. The series were first differenced and the Johansen tests reapplied. In first differences all price series reject the null and accept the alternative hypothesis of cointegration. Cointegration in one variable suggests a stationary I(0) series. Since all spot and futures series for each oil commodity are of the same order of integration i.e. I(1) in levels, they are candidates for cointegration. Test statistics are reported in Table 3.1.

Table 3.1

Johansen Tests for Unit Root

Series	Levels	Differences
Brent Crude S_t	4.426	30.281
F_{t-1}	4.946	23.343
F_{t-2}	4.964	35.621
F_{t-3}	5.200	20.496
WTI Crude S_t	6.783	64.810
F_{t-1}	6.695	71.835
F_{t-2}	6.129	66.501
F_{t-3}	5.073	67.277

H0: there are no cointegrating relationships, i.e. there is no integration.
The critical value at 5% = 9.243

Tests for Appropriate VAR Length

While this study employs the Johansen ML technique for testing cointegration, Hall (1991) suggests that the procedure may be sensitive to the choice of VAR order, with that sensitivity manifesting itself in the test statistics. If the VAR order is set too low then serial correlation will generally result, while a VAR order set too high could result in small a sample effect. In response to this, the effect of varying the VAR specification should be examined when applying the Johansen technique. The first stage of the Johansen procedure is the selection of an unrestricted VAR(k) process. Hall proposes that to choose k one should select an arbitrarily high order for the VAR and then use likelihood ratio tests to ascertain the validity of restrictions imposed by successive reductions of the model's order. The correct order of the VAR is deemed to have been found when a restriction on lag length is rejected.

Following Hall, LR tests were carried out on VAR lengths reducing from 5 to 1 lags. Inspection of the results from these tests, see Table 3.2 shows that the most appropriate VAR order is not always unambiguous. For example, the Brent one-month futures contract rejects a restriction on the VAR order from 4 to 3 lags, but accepts a second order VAR as a valid restriction on a third order VAR, while rejecting the restriction from VAR(2) to VAR(1). Hall recognises that the point at which restrictions become invalid may not be unique. Under such circumstances there is no clear decision rule. In this study, given the relatively small sample for Brent, a rejection on a higher order restriction is overlooked when a lower order restriction is accepted.

Table 3.2

LR Tests for Correct VAR Order

Contract	Order Restriction				VAR(k)
	5-4	4-3	3-2	2-1	
Brent F_{t-1}	7.930	22.570	7.946	24.976	2
" F_{t-2}	8.858	3.174	46.390	51.970	3
" F_{t-3}	1.904	59.592	11.148	30.738	4
WTI F_{t-1}	3.818	7.748	6.786	17.024	2
" F_{t-2}	8.708	0.604	32.580	73.776	3
" F_{t-3}	1.308	58.428	57.118	57.070	4

The critical value $\chi^2(4) = 9.49$

3.6 EMPIRICAL RESULTS

Long-run Efficiency and Cointegration

The order of integration determined, we use cointegration to examine efficiency within each market, investigating whether the spot price S_t and the futures price $F_{t-n,t}$ (where n = 1, 2 and 3 months to maturity), are cointegrated.[43] Linear combinations of the spot and futures price series which have a unit cointegrating vector indicate that their difference is stationary and therefore imply that futures prices are efficient predictors of the spot price. Using the Johansen cointegration procedure we test the null hypothesis that there are zero cointegrating vectors between the spot and futures series against the alternative that there is one cointegrating vector.

For WTI crude oil over all maturities test statistics reject the null at the 5% level of significance suggesting that cointegration is present. In the case of Brent crude, cointegration was established between the spot and the one and two-month futures contracts but not the three-month contract. Since the spot and three-month futures fail to cointegrate for Brent we do not proceed further with this contract. Results are reported in Table 3.3 and, for the purpose of illustration, graphs of spot and nearby futures contracts are given for Brent and WTI in Figures 3.1 and 3.2 respectively. The finding of cointegration, whilst a necessary condition for market efficiency, is not a sufficient condition and so further analysis is required.

Tests on cointegrating regressions for spot and futures were carried out to determine whether the second condition for market efficiency could be satisfied i.e. that the

[43] For reasons of convenience terminology will be, henceforth, in terms of current prices.

restrictions of a zero intercept and unit cointegrating vector (α=0 and δ=1 in equation (3.5b)) is valid. This restriction cannot be tested using standard *t*-statistics, as explained in Section 3.3, but can be tested using the Johansen test statistic. This a likelihood ratio test which is χ^2 distributed. Using this test the hypothesis α=0, δ=1 was accepted for all three maturities for WTI, but was rejected in the two remaining cases for Brent at the 5% level. Results are presented in Table 3.3. Investigations into the effect of using different VAR orders showed these results to be sensitive to the VAR specification. This finding lends support the policy of finding the most appropriate VAR order prior to implementing the Johansen procedure.

While the finding of cointegration for up to three months to maturity for WTI and to two months to maturity for Brent may *suggest* that their respective futures markets are unbiased predictors for those time horizons, results from the parameter restriction on the cointegrating regressions do not support this conclusion in all cases. Tests on the cointegrating equations' parameters indicate that acceptance of the unbiasedness hypothesis holds only for WTI crude. Moreover, while this finding suggests efficiency in the long-term for WTI it ignores the possibility of there being substantial deviations from that relationship in the short-term. Error-correction models need to be investigated before reliable comments can be made as to the precise nature of efficiency.

Table 3.3

Johansen Tests for Cointegration of Spot and Futures Prices

$$S_t = \alpha + \delta F_{t-n,t} + \epsilon_t$$

Regressor	Cointegration	α=0, δ=1
Brent F_{t-1}	36.040	22.632
F_{t-2}	20.860	10.583
F_{t-3}	8.947	—
WTI F_{t-1}	44.555	1.319
F_{t-2}	32.035	3.122
F_{t-3}	20.054	2.752

Columns labelled 'cointegration' are tests for the null hypothesis that there are no cointegrating relationships between the spot and futures prices. The critical value at 5% = 15.67. The column labelled 'α=0,δ=1' are Johansen tests of the joint restriction on the cointegrating regressions. The test is χ^2 distributed with the critical value of $\chi^2(2)$ at 5% = 5.99

Figure 3.1

Brent Spot and Nearby Futures Prices
(Monthly observations July 1989 to July 1993)

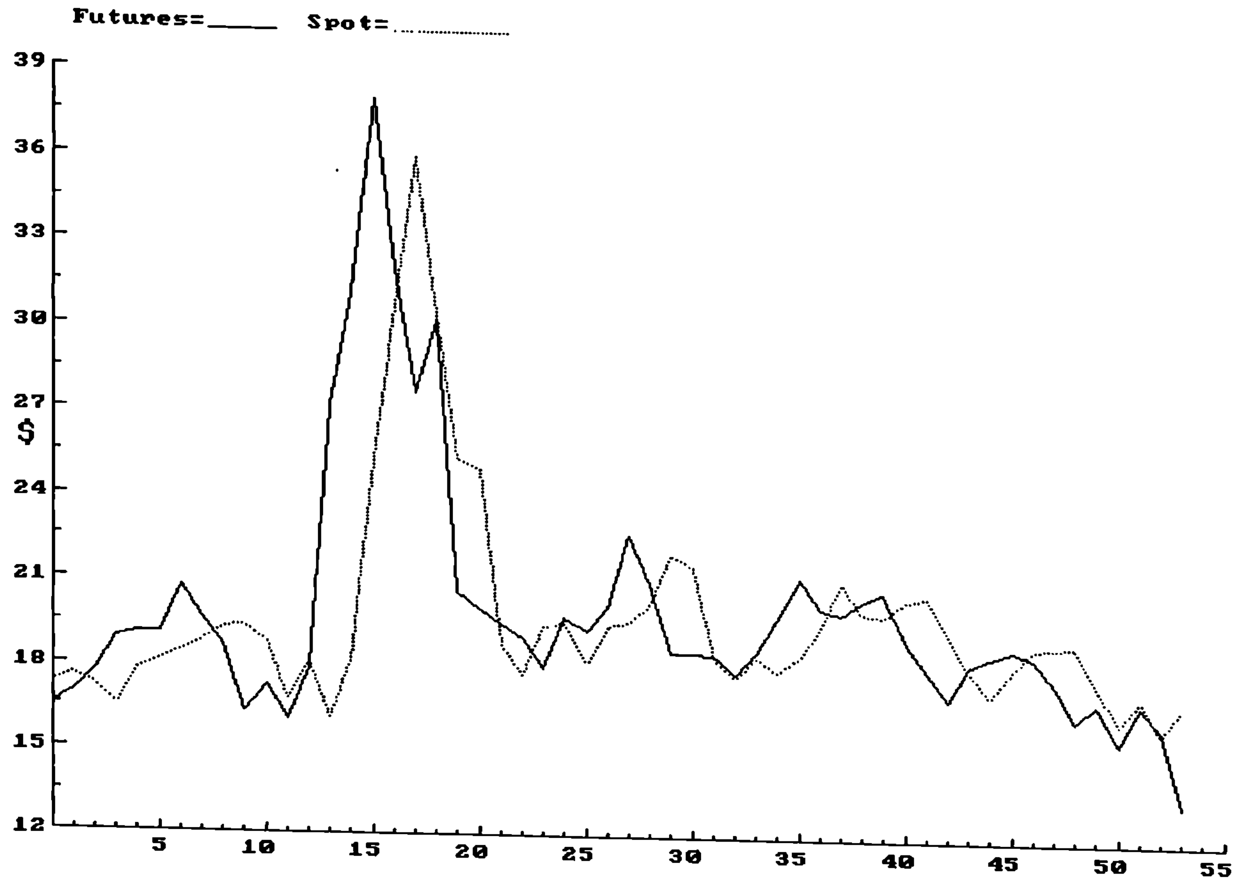
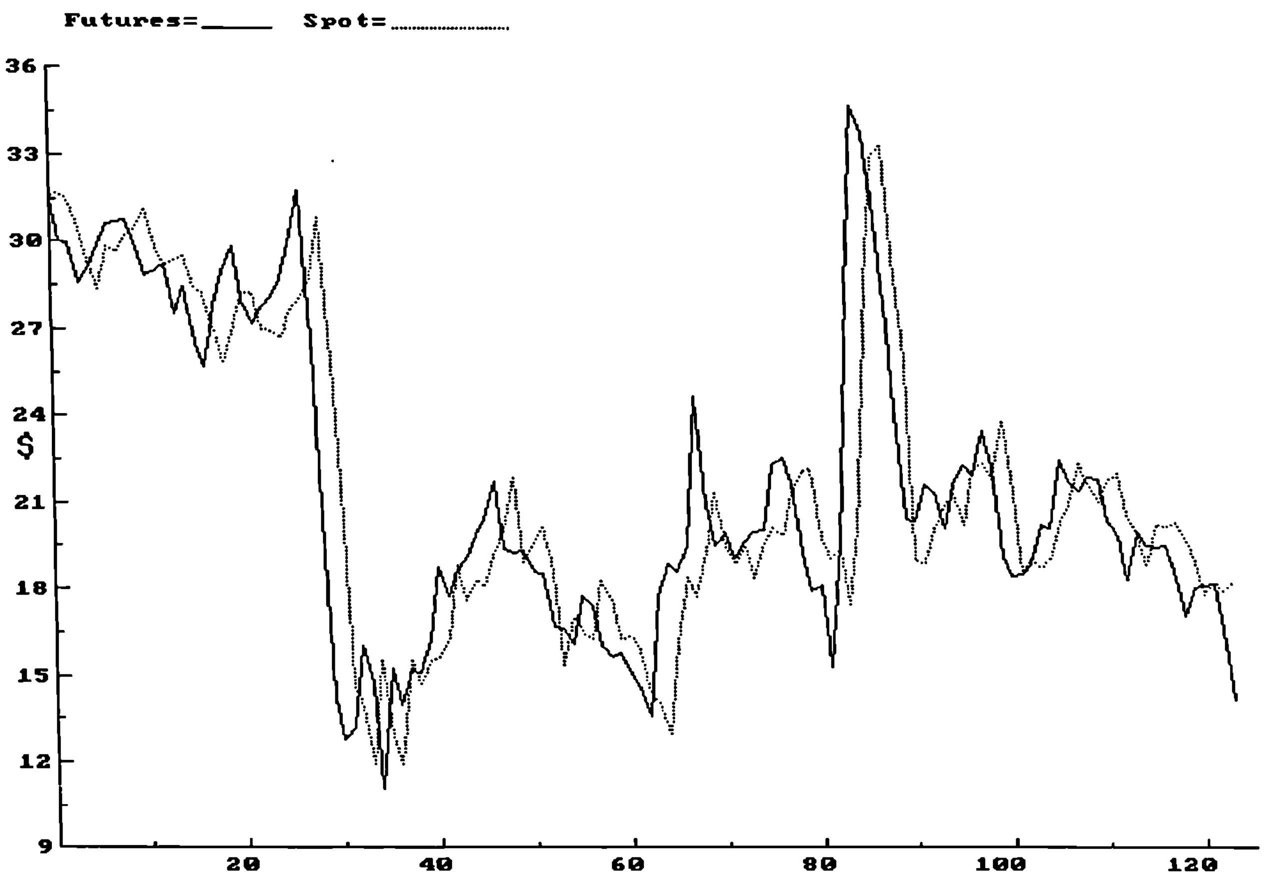


Figure 3.2

WTI Spot and Nearby Futures Prices
(Monthly observations Sept 1983 to July 1993)



Short-run Efficiency and the ECM

The third condition for efficiency was investigated by constructing and estimating ECMs for each cointegrating regression, as specified in equation (3.6). In order to test the restriction $\phi=0$, a series of ECMs including up to three lags of the dependent variable on the RHS were constructed for each cointegrating regression.

Lagged values of the dependent variable, ϕ_i, were found to be significant for the two and three-month WTI contracts thus violating the condition that autoregressive terms in the ECM should be zero. As such short-term efficiency is rejected for the two longer maturity horizons. On the basis of these results a Wald test was employed to test the parameter $-\rho=\gamma=1$ in equation (3.6) for the one-month WTI contract alone. Test statistics strongly suggest rejection of this third condition for short-term efficiency for forecast horizons of one month. These results highlight the importance of using ECMs in tests of efficiency. Results are presented in Tables 3.4. Given that none of the contracts considered are efficient in the short-term, we do not proceed to test the final ancillary condition that the parameter values of the ECM are stationary over time.

On the basis of our tests we find WTI crude oil futures to be unbiased predictors of the future spot price in the long-term for (at least) three months from maturity, while Brent crude futures are biased predictors for all months considered. It is not possible, however, to isolate the precise cause of such long-term inefficiency for the Brent market. Proceeding to tests of short-run efficiency for WTI crude, results from this analysis suggest that all maturities are inefficient in the short-term.

Table 3.4

Error-Correction Models for WTI Crude Spot and Futures

$$\Delta S_t = \alpha + \gamma \Delta F_{t-n,t} + \rho(S_{t-1} - F_{t-n,t-1}) + \epsilon_t$$

Series (F_{t-n})	α	γ	ρ	ϕ_1	ϕ_2	Wald test
F_{t-1}	-.008 (-.094)	.684 (3.501)	-.475 (-2.508)	—	—	398.85
F_{t-2}	-.2E-3 (-.028)	.196 (1.115)	-.317 (-1.979)	.492 (2.981)	—	—
F_{t-3}	.002 (.229)	.387 (2.244)	-.433 (-3.181)	.504 (3.434)	.340 (2.468)	—

Figures in parentheses are *t*-statistics.
The Wald test is for the parameter restriction $\rho=\gamma=1$ and is a $\chi^2(2)$ test with a critical value at 5% = 5.99
Models were estimated with MA(n-1) errors

3.7 SUMMARY AND CONCLUSIONS

The purpose of this chapter was to investigate the issue of market efficiency in the long-term and short-term for Brent crude oil and WTI crude oil spot and futures markets. Whilst previous studies have adopted cointegration to test for efficiency this practice describes efficiency only in the long-term; while there still remains scope for profitable arbitrage in the short-term. Consequently tests of efficiency require the formation of ECMs in order to capture the short-term dynamics of information flows.

Results suggest that there is long-term efficiency in the WTI futures markets only, with that efficiency holding for at least three months from maturity. While all the maturity groups of futures contracts considered here do cointegrate with their spot markets, it is clear from the results that cointegration alone does not assure long-term efficiency, as evidenced by the Brent market. Moreover, although all three contracts considered here for WTI do cointegrate and are also efficient in the long-term, this is not expected to extend to longer maturities, and the relationship should eventually break down. Given the link between future's efficiency and the information set this is an intuitively agreeable suggestion.

Despite the above, the absence of cointegration need not necessarily preclude efficiency. Schroeder and Goodwin (1991), argue that while the markets' failure to cointegrate at longer maturities is usually interpreted as an indication of inefficiency given Granger's (1986) assertion that spot and futures prices represent the same commodity, an alternative explanation is that at longer maturities spot and futures prices no longer represent the same commodity, hence the lack of cointegration. One explanation for this can be given with the example of a hedger who wishes to liquidate a futures position prior to its maturity. Given the convergence of spot and futures prices as maturity declines, a longer maturity futures contract will face more basis risk than a shorter maturity future. As a consequence, the two futures contracts will not represent the same asset since they have different basis risk profiles. Thus, whilst the futures contracts both represent the same commodity, they are different assets. Moreover only one of these assets (the shorter maturity contract) will be the 'same' as the spot commodity. Logically, therefore, the longer maturity contract cannot be the same as the spot, hence they will not cointegrate.

Since the parameter restrictions on the cointegrating regression fail to hold for Brent crude for the one-month and two-month maturity contracts we do not proceed to test for short-term efficiency in that market. The same restrictions were supported for WTI, however, and so long-term efficiency is established. The rejection of the joint hypothesis, and so the rejection of efficiency for Brent crude, raises important questions in terms of policy implications especially since the precise cause of rejection cannot be clearly identified. As noted by Hakkio and Rush (1989), the policy implications from the presence of a risk premium are different to those from the inefficient use of information. Furthermore, the implications for market participants will differ depending upon the cause of rejection. If information is not used efficiently then profitable speculative opportunities will result allowing speculators to increase their expected utility. A market characterised as risk averse, on the other hand, would also lead to rejection of the joint hypothesis but would not necessarily imply unexploited profit opportunities.

While the precise reason for rejection of the joint hypothesis cannot be identified, we may conjecture that the presence of a risk premium is the primary cause. This assertion is based on the evidence elsewhere in this thesis which broadly support the notion of oil futures markets being informationally efficient.

In the short-term the NYMEX futures contract is found to be inefficient for all contracts considered, but overall we see that the NYMEX futures market is more efficient than the IPE Brent futures market. This result has intuitively straight-forward explanations related to the relative sizes and maturities of the two markets. As was seen in Chapter 1 (Table 1.2) the NYMEX crude oil futures market has a trading volume approximately six times that of its UK peer, and has been in existence five years longer. Moreover the UK spot market is, to some extent, open to manipulation since it is monopolised by three main oil companies; BP, Elf and Shell. As such we can explain the differences in the relative efficiency of the two markets in terms of their size and trading freedom.

CHAPTER 4*

PRICE DOMINANCE BETWEEN OIL SPOT AND FUTURES MARKETS

4.1 INTRODUCTION

Price discovery describes the ability of one market to detect information which will later influence prices in another market. The action of discovering such information and impounding it into prices prior to a like response elsewhere is referred to as price dominance. Since spot and futures markets represent the same commodity their prices will generally respond in the same way to a given information event. This is assured by the actions of arbitrageurs whose trading will remove exploitable inter-market price differences, thus reducing absolute price differences to the point where they reflect the cost differentials between markets. Such mutual price responses are a necessary condition for dominance relationships.

We can identify four types of information flow between markets, each indicating a different level of price dominance. In the case of there being no information flows markets are deemed to be unrelated and dominance is not present. If information flows are present and unidirectional then one market is said to dominate the other. In addition to these two polar cases one can identify relationships where information feedback occurs. If feedback is symmetric then information is impounded in both markets contemporaneously, as such the markets are related but neither dominates the

* The main elements of this Chapter have appeared in Antoniou and Foster (1992b, 1993b) and Foster (1993).

other. If information feedback is asymmetric then dominance is again present.

It is often assumed that in the initial period of futures trading the spot market will be dominant due to thin trading volumes (and so low promulgation of information) in the futures market. Once the futures market has matured, however, it is commonly expected to assume dominance since it faces fewer market frictions, such as transaction costs, and has greater liquidity.[44] Section 2.2 provides a discussion of these attributes. This assumption implies the expectation that dominance varies over time; futures markets may indeed become more dominant over time, although this does not imply that the situation will not reverse itself. A related issue arises from a number of previous studies into dominance relationships which have found different markets to exhibit different dominance characteristics due to a number of factors. Overall, dominance is related to the integratedness of markets, and can be affected by such factors as the maturity of a futures market, trading volume, institutional arrangements, and market structure. Where markets are perfectly integrated, those markets will assimilate new information at the same time and so react simultaneously to news events. If markets are less than perfectly integrated one market will be better able to register the price-implications of new information than the other and dominance will arise.

A number of methodologies have been adopted to investigate price dominance in spot and futures markets. The essence of these techniques is the same in that they examine

[44] Spot markets may dominate futures markets for reasons other than thin trading volumes in the futures market. This area is further developed later in the chapter.

the different response-times of spot and futures markets to perceived information events;[45] the relative timing of these mutual responses being used to identify dominance. The methodologies employed in previous work can be categorised into two main groups. In the first category Granger and Sims causality tests have been employed to determine lead-lag relationships between spot and futures markets. Studies here include Oellermann *et al* (1989), Koontz *et al* (1990), and Chan (1992). In the second category linear regressions (implicitly) containing error-correction terms have been used to calculated a coefficient of dominance, see Garbade and Silber (1983), Oellermann *et al* (1989), Schwarz and Laatsch (1991), and Schroeder and Goodwin (1991).

In this chapter cointegration techniques are employed to establish a link between spot and futures markets. The presence of cointegration suggests an underlying error-correction model (ECM), and it is through an ECM that this study presents a synthesis of the Garbade and Silber (1983) model with the dynamic specification associated with Granger causality. In this way we incorporate all the different channels through which information is transmitted between markets. The model we derive is used to generate point estimates of dominance. Estimates using the Garbade and Silber model are also provided for purposes of comparison. While point estimates are used to illustrate the relevance of our model, it is our contention that point estimation fails to account properly for the true temporal nature of price dominance, leading us to estimate dominance within a time-varying parameter framework. This is achieved by

[45] Information events are not explicitly modelled, rather price movements in both spot and futures markets are deemed to be a reaction to new information.

utilising the Kalman Filter method previously outlined in Chapter 2. The subject matter of this investigation is the UK market for Brent crude and the US market for WTI crude. A further dimension is added to this study by examining changes in dominance relationships around key events of the 1990-91 Gulf Conflict in order to better understand the effect of market characteristics on dominance.

In brief, we find that previous methodologies have failed to account for all routes through which information is transmitted between spot and futures markets, and we demonstrate that dominance relationships can exhibit strong temporal characteristics. This observation leads us to recommend the use of time-varying parameter techniques to investigations in this field. In addition, dominance patterns are seen to be determined in part by the rate and type of information arriving onto the market.

The chapter is organised as follows. The next section describes the models used in the current literature to explore dominance and also presents the theoretical model to be used for assessing dominance in this study. Section 4.3 details the use of the Kalman Filter technique for time-varying parameter estimation, while Section 4.4 describes the methodology employed by this analysis, elaborating on the use of the techniques explained in the previous section. In Section 4.5 we provide details of the data used for the investigation and report some preliminary results. The main empirical results are reported in Section 4.6, with the final section providing a summary and conclusions.

4.2 A Theoretical Model of Price Dominance

As indicated in the previous section, dominant-satellite relationships exist only in the presence of asymmetric information flows. If the information flow asymmetries are such that prices in market X affect prices in market Y, but the reverse does not hold then Y is a pure satellite of X. In this case X exhibits strong dominance over Y and information flows may be characterised as asymmetric-unidirectional. If prices in X generally affect prices in Y, but prices in X also adjust to price changes in Y (although to a lesser extent) then Y is a partial satellite of X. As such X is characterised as weakly dominating Y and information flows exhibit asymmetric-feedback. Where both markets react to information together the markets may be deemed perfectly integrated and the futures contract will provide a perfect substitute for a spot position. The possibility of there being no feedback at all is deemed highly unlikely since it would imply a complete breakdown in the links between the two markets to the extent that the futures contract is no longer related to the spot asset.

In perfect and complete markets, spot and futures markets for the same commodity will exhibit a contemporaneous reaction to new information. Since real markets are neither complete nor perfect, due to market frictions, we expect information asymmetries to be present. In most cases this implies information being discovered first in futures markets given their relative freedom from market frictions. We examine the nature of such asymmetries by assessing price dominance between spot and futures markets. Such analysis rests squarely on the links between spot and futures prices, and this section discusses such associations in terms of both the difference between the markets (the basis), and their lead-lag relationships.

The basic underlying relation between spot and futures prices can be described with the equation for the 'fair,' or theoretically correct, futures price. Here the fair futures price at time t, for a contract which matures at time T i.e. $F^*_{t,T}$ is equated to the spot price, S_t, plus the cost of carrying the spot position forward to period T. Following Gibson and Schwartz (1990) we utilise the following fair futures pricing formula which specifically deals with the pricing of futures on storable commodities.[46]

$$F^*_{t,T} = S_t e^{(r-\delta)(T-t)} \tag{4.1a}$$

The cost of carry is given by (r-δ)(T-t) where r is the 'risk-free' rate of interest, δ is the convenience yield (or alternatively the cost of storage), and T-t is the time remaining to contract maturity. The term (r-δ) represents the net 'dividend' yield accruing to the owner of the physical commodity. As is evident from the relationship described in equation (4.1a), when the futures contract reaches maturity i.e. when t=T, the cost of carry will be zero and the futures price must equate to the spot price. While the two price series equate at maturity, they are also expected to remain closely related prior to that point. As we move further from maturity (t<T), spot and futures prices will differ but such price differentials should be limited to the cost of carry,

[46] If the futures market prices futures contracts correctly there will be no arbitrage opportunities such that;

$$F^*_{t,T} - F_{t,T} = 0$$

where $F_{t,T}$ is the actual futures price. From the above equation it follows that;

$$F_{t,T} = S_t e^{(r-\delta)(T-t)}$$

otherwise the markets will offer arbitrage opportunities. Spot and futures markets are thus held together over the long-run, with this relationship being assured by the actions of market agents. It is the notion of arbitrageurs exploiting departures from the cost of carry relationship which form the basis of the Garbade and Silber (1983) approach to price dominance.

The Garbade & Silber Approach

Garbade and Silber (1983) present a model of price dominance derived from the fair futures formula presented in equation (4.1a). The model provides both an indication of the source of price discovery and a measure of the strength of one market's dominance over another. The development of the model begins from a state of perfect market conditions where, amongst other things, there are no costs to storage, no convenience yields, and no restrictions on arbitrage activity. Under these assumptions the fair futures price for storable commodities is adjusted for financing costs only as shown in equation (4.1b) below, where δ is set to zero.

$$F^*_{t,T} = S_t e^{r(T-t)} \tag{4.1b}$$

The above equation states that the current futures price is equal to the spot price plus a financing cost which applies until contract maturity. The financing cost represents the premium due to the deferred payment on the futures contract. The analysis of price dominance, however, requires the futures price to be adjusted further. Garbade and Silber propose that an examination of price discovery between spot and futures markets necessitates the use of a 'cash equivalent' futures price, in order that the dynamics of contemporaneous spot and futures prices can be analysed net of financing costs. To derive the cash equivalent futures price, F_t', we must remove the financing costs of holding the futures position. This is achieved using the following formula as proposed by Garbade and Silber, where prices are expressed in logarithms;

$$F_t' = S_t = F_{t,T}^* - r(T-t) \tag{4.2}$$

The Garbade and Silber, hereafter GS, model of simultaneous price dynamics between spot and futures prices based upon the notion that the correlation of their contemporaneous prices is a positive function of the supply of arbitrage. Where these relative prices violate a simple equality in which the cash equivalent futures price is equal to the spot price (equation 4.2), then an infinite amount of arbitrage activity will be supplied until the pricing equality is restored.

GS then extend the model to the more realistic case of imperfect markets where spot and futures markets have separate pricing functions, again linked by arbitrage activity. When markets are imperfect the supply of arbitrage activity will be finite, and that supply will dictate the degree to which the spot and futures markets are linked. In this way the authors describe the degree to which spot and futures prices exhibit a similar response to information as being a function of the amount of arbitrage activity forcing those prices to move together. Thus, if there is no arbitrage between the spot and futures markets then their prices will evolve independently so that those prices have no implications for each other. In this case the price discovery and hedging functions of futures contracts are precluded. By contrast, if the supply of arbitrage is infinitely elastic then the spot and futures markets will have a common price evolution and a futures contract will act as perfect substitute for a spot position.

Between the polar cases lies the expected relationship where spot and futures markets are closely related due to a finite supply of arbitrage. Here the greater the supply of arbitrage activity, the more highly correlated will be the markets' response to innovations, and so the less likely their prices will be to drift apart. In addition, where price divergence does occur, it will be eliminated more rapidly when the supply of arbitrage is elastic. By suggesting that spot and futures prices will have such a common evolution, GS are essentially suggesting what Granger (1986) proposed, namely that the spot and futures prices will cointegrate, with that cointegrating process being driven by arbitrage. The more elastic the supply of arbitrage, the greater will be the expected level of integration of spot and futures markets, such that where arbitrage has an infinite supply, the markets will be perfectly cointegrated.

Exploiting this link with cointegration, we demonstrate below that the GS arbitrage model may be represented as the error-correction term implied by a cointegrating relationship. GS specify the following system where F_t' and S_t are defined as above,

$$\begin{bmatrix} S_t \\ F_t' \end{bmatrix} = \begin{bmatrix} \alpha_s \\ \alpha_f \end{bmatrix} + \begin{bmatrix} 1-\beta_s & \beta_s \\ \beta_f & 1-\beta_f \end{bmatrix} \begin{bmatrix} S_{t-1} \\ F_{t-1}' \end{bmatrix} + \begin{bmatrix} \epsilon_t^s \\ \epsilon_t^f \end{bmatrix} \tag{4.3a}$$

Equation (4.3a) can be expressed in estimable form as the following vector autoregressive, VAR(1), model.

$$\begin{bmatrix} S_t - S_{t-1} \\ F_t' - F_{t-1}' \end{bmatrix} = \begin{bmatrix} \alpha_s \\ \alpha_f \end{bmatrix} + \begin{bmatrix} \beta_s \\ -\beta_f \end{bmatrix} \begin{bmatrix} F_{t-1}' - S_{t-1} \end{bmatrix} + \begin{bmatrix} \epsilon_t^s \\ \epsilon_t^f \end{bmatrix} \tag{4.3b}$$

which can be rewritten in single equation form as a system of linear equations containing error-correction terms,

$$\Delta S_t = \alpha_s + \beta_s\left[F'_{t-1} - S_{t-1}\right] + \epsilon_t^s \tag{4.4a}$$

$$\Delta F'_t = \alpha_f + \beta_f\left[S_{t-1} - F'_{t-1}\right] + \epsilon_t^f \tag{4.4b}$$

The parameters β_s and β_f can be estimated using standard OLS procedures. Once found the parameter values are used to estimate the coefficient of dominance, Γ, given by the ratio $\beta_s/\beta_s+\beta_f$. In order to prevent the computation of a negative dominance coefficient GS constrain both β_s and β_f to be non-negative, following which the dominance ratio will assume a value between zero and one. The value of Γ signifies the relative dominance of the spot and futures markets. If $\Gamma=1$ then by implication $\beta_f=0$, and the futures market exhibits strong dominance over the spot market. Conversely if $\Gamma=0$ then $\beta_s=0$ and the futures market is strongly dominated by the spot market. For intermediate values of Γ the two markets exhibit a feedback relationship with relative dominance indicated by the size of Γ. For $.5 < \Gamma < 1$ the futures market weakly dominates the spot market, and vice versa for $0 < \Gamma < .5$. When $\Gamma=.5$ feedback is symmetric and information is contemporaneously impounded in both prices. Here there is no dominance as such since the markets are perfectly integrated.

Granger Causality

A widely adopted technique for determining dominant-satellite relationships is due to Granger (1969). Granger causality tests have been used to identify lead-lag relationships between markets as a way of inferring price dominance. As such the tests are not meant to imply causality in its true sense, rather they indicate the different timings of common responses to information events. If causality is to be assigned then it is information which causes both spot and futures prices, with futures markets normally being more responsive that to information.[47] Thus, the futures market acts as a medium through which information is transmitted to the spot market, rather than being the 'information' itself. This distinction has been summarised as the futures market acting as the messenger, not the message.[48] The dominance relationship between spot and futures prices is examined by estimating the regressions,

$$\Delta S_t = a_0 + a_1 \Delta F^{\prime}_{t-1} + a_2 \Delta S_{t-1} + e_t^s \tag{4.5a}$$

$$\Delta F^{\prime}_t = b_0 + b_1 \Delta S_{t-1} + b_2 \Delta F^{\prime}_{t-1} + e_t^f \tag{4.5b}$$

In this respect it is the significance of the parameters a_1 and b_1 which are examined as a way of inferring which market discovers information first. If a_1 is statistically different from zero, and b_1 is not statistically different from zero ($a_1 \neq 0$, $b_1 = 0$) then futures markets exhibit strong dominance over spot markets. For the case where $a_1 = 0$, $b_1 \neq 0$ spot markets strongly dominate futures markets. Weak dominance is consistent with the parameters a_1 and b_1 being statistically significantly different from zero[49]. Models like those in equation (4.5) essentially represent the actions of hedgers and speculators adjusting their market positions to the arrival of new information. As

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[47] As proposed in Chapter 2, it is the enhanced information discovery due to futures markets which affects spot market prices, and not the futures market itself.

[48] Stoll and Whaley (1988) note that by expanding the number of channels through which messages (information) can travel, futures markets act as one of the economy's messengers. This aspect has also received attention from Antoniou and Holmes (1992).

[49] Symmetric feedback is also consistent with this result.

information arrives futures and spot prices will move and speculators in both the spot and futures markets will trade with their trading exerting pressure on prices. As prices change, hedgers will be forced to adjust their positions in the futures market leading to further price change there as the supply and demand of futures contracts change.

Cointegration

The theory of cointegration (see Chapter 3) can be used to unify the GS and Granger models of price adjustment to information. As a starting point one may consider the spot and futures price at the maturity date of the futures contract, that is, where the two prices must equate. This singularity is the long-run equilibrium point defined by cointegration. Naturally, prior to the singularity being attained, i.e. as we move further away from maturity, the spot and futures prices will differ. However, such price differences will face constraints as detailed earlier in this section. Cointegration and the ECM serve to provide a model of the processes through which the markets are held together in this fashion, i.e. the ECM provides a model of the information routes created by the trading decisions of arbitrageurs, speculators and hedgers.

As detailed in the previous chapter, where two variables cointegrate there exists an ECM which describes the short-run dynamic adjustment of those variables.[50] The ECM consists of lagged first differences from the cointegrating market together with a once-lagged error-correction term. Both of these variables represent channels through which information may flow between markets. By omitting the error-correction term Granger causality tests fail to account for information transfer occurring through risk

[50] Equation 3.6 specifies a general representation of an ECM.

arbitrage; i.e. the basis speculation considered by the GS model. Similarly the GS methodology does not consider adjustments to prices through hedging, speculation, and general arbitrage as reflected in the lagged difference terms of the Granger causality model. As a consequence investigations into dominance which have adopted the above methodologies have overlooked all possible information channels.

The model presented here is a synthesis of the Granger and GS models, generalising the model offered by GS by including the lagged returns of related markets found in the Granger causality model. The resultant General Dominance Model (GDM) may be viewed as a form of ECM derived from a cointegrating relationship. The form of the GDM is specified *a priori* and includes only those variables which have been identified as explaining the links between markets. The resulting GDM representation is consistent with both the specification of the GS model, of which the GDM is a generalised version, and with the focus of the Granger model.[51] The GDMs are illustrated in (4.6a) and (4.6b) below as single equations from a VAR system.

$$\Delta S_t = \alpha_0 + \alpha_1 \Delta F'_{t-1} + \alpha_2 \left[F'_{t-1} - S_{t-1}\right] + e_t^s \qquad (4.6a)$$

$$\Delta F'_t = \beta_0 + \beta_1 \Delta S_{t-1} + \beta_2 \left[S_{t-1} - F'_{t-1}\right] + e_t^f \qquad (4.6b)$$

The GDM marks an improvement in testing dominance in that it captures information flows through two channels; the lagged difference terms from the standard Granger model and the lagged error-correction term from the GS model. From the model in (4.6) we calculate a coefficient of dominance in the style of the GS coefficient with

[51] As explained above Granger causality focuses upon the significance of lagged other-market variables as a way of inferring dominance.

a generalised dominance ratio specified as follows;

$$\Gamma^* = \frac{\alpha_1 + \alpha_2}{\alpha_1 + \alpha_2 + \beta_1 + \beta_2}$$

4.3 TIME-VARYING PARAMETER ESTIMATION

Previous studies using point estimation to identify dominance are prone to the problem of allowing important changes in dominance to go undetected. A number of studies have recognised that there are no *a priori* reasons to expect that dominance will not change over time, and have tracked its evolution by dividing their samples into sub-periods. This method is, however, unreliable when the dominance coefficient is sensitive to the assignment of the sub-period. Such sensitivity will have adverse effects upon inferences made from standard regression analysis. In response to this we estimate the generalised dominance ratio, Γ^*, within a time-varying parameter framework to test for the temporal stability of that coefficient. When dominance is found to be temporally unstable, the results of models using standard OLS regression cannot be relied upon since OLS assumes parameter stability. The Kalman Filter, see *inter alia* Kalman (1960) and Harvey (1981, 1989), is thus adopted to model time-varying parameters. The technique allows the regression parameters to evolve through time according to a stochastic process; assumed to be a random walk for the purpose of this investigation. The random walk assumption is motivated by the work of Ross (1989), where price changes are shown to depend upon the rate of information arrival which is assumed to be characterised by a random walk process. This area has received attention in Chapter 2 of the thesis.

In cases where the behaviour of a time series is complex it is possible to approximate its behaviour using a simplified modelling structure; the state space form. As explained in Chapter 2, a state space representation consists of two parts: the measurement equation which describes how the time series under consideration is generated from the state variables, and the transition equation which describes the evolution of those state variables. Following the example supplied by Harvey (1989), the intuition underlying the state space form for the case of time-varying parameter estimation can be explained with a simple regression model containing time-varying parameters. Revisiting the time-varying parameter model presented in equation (2.14) which is re-expressed in equation (4.7) below, the state space formulation sets up the state vector, α_t, so that it contains all the information necessary to describe the system with as small a number of elements as possible.

$$Y_t = X_t \alpha_t + \epsilon_t \tag{4.7}$$

where $\mathbf{Y}_t$ is the n×1 vector of endogenous variables, $\mathbf{X}_t$ is an n×m matrix of predetermined variables and ε_t is an n×1 vector of serially uncorrelated errors with zero mean and constant covariance matrix, $\mathbf{H}_t$. In the above α_t represents the m×1 vector of time-varying parameters; the state vector. Equation (4.7) represents the measurement equation. While the elements of α_t will not be observable, they are generated by a first-order Markov process as defined below;

$$\alpha_t = T \alpha_{t-1} + u_t \tag{4.8}$$

In the above **T** is a known mxm matrix and $\mathbf{u}_t$ is a vector of serially uncorrelated errors with zero mean and constant covariance matrix, $\mathbf{Q}_t$. Equation (4.8) above is the transition equation. As described in Chapter 2, the Kalman Filter presents a recursive procedure for finding the optimal estimator of the state vector α_t given information available at t.

4.4 METHODOLOGY

The Kalman Filter

In this study we wish to estimate the parameters in equation (4.6) as they vary over time. Thus we may express equations (4.6a) and (4.6b) in state space form in equation (4.9) where $\mathbf{P}_t$ is the vector of spot and futures returns and $\mathbf{E}_t$ is the vector of error-correction terms. Furthermore, Λ_t represents the state vector of time-varying parameters on $\mathbf{P}_t$, and Π_t is the state vector of time-varying parameters on $\mathbf{E}_t$. Similarly **c** is the vector of constant intercepts, and ε_t is the vector of error terms. Thus the measurement equation becomes;

$$P_t = c_t + P'_{t-1}\Lambda_t + E'_{t-1}\Pi_t + \epsilon_t \tag{4.9}$$

where $P_t = \begin{bmatrix} \Delta S_t \\ \Delta F'_t \end{bmatrix}$ $\quad E_t = \begin{bmatrix} F'_t - S_t \\ S_t - F'_t \end{bmatrix}$ $\quad \Lambda = \begin{bmatrix} 0 & \beta_1 \\ \alpha_1 & 0 \end{bmatrix}$ $\quad \Pi = \begin{bmatrix} \alpha_2 & 0 \\ 0 & \beta_2 \end{bmatrix}$

Similarly the transition equation may be specified as follows where M and N are identity matrices as dictated by the earlier assumption that the parameters evolve according to a random walk:[52]

$$\begin{aligned} \Lambda_t &= M\Lambda_{t-1} + \eta_t \\ \Pi_t &= N\Pi_{t-1} + \omega_t \end{aligned} \tag{4.10}$$

Thus the measurement equation (4.9) describes how the dependent vector is generated from the state vectors, while the transition equation (4.10) describes the temporal evolution of the state vectors. Having extracted the series Λ_t and Π_t we may use them to calculate Γ_t^*.

The GDM methodology has one further distinction from the GS methodology in that the latter restricts the signs on its model's coefficients (β_s and β_f), to be positive on the grounds that there is no theoretical reason to expect the parameters to have negative signs. While this is generally true in the absence of convenience yields, it is possible for the parameter signs to be negative. To ensure positive signs the GS methodology sets negative parameters to zero. This practice, however, has the undesirable effect of imposing a pure dominant-satellite relationship. As an alternative to this we take absolute parameter values, given that it is the response to price change rather than the sign of the price change in which we are interested.

[52] Since M and N are identity matrices their appearance in equation (4.10) is somewhat trivial and they may be omitted.

4.5 Data and Preliminary Analysis

The Data

While some previous studies have used sampling frequencies lower than daily data, their use has been questioned for the purposes of investigating price dominance. The reason for this is that given the continuous nature of information flows we should not expect low frequency data to fully demonstrate relative price movements. This argument can be extended to suggest that intraday data should be used for such studies. While this is true to some extent, such information is not available for oil spot prices. Moreover, Hudson and Purcell (1985) argue that although intraday data has its attractions, such high frequency data is impractical for widespread use by market agents.[53]

The measurement of storage costs and the calculation of any possible convenience yields presents complications to the study of spot-futures relationship, in that the cost of carry will clearly be increased due to storage costs and lowered if a positive convenience yield is present. Data availability restrictions and limitations on the scope of this study prevent attention being paid to storage costs convenience yields. As a consequence we assume their opposite effects to sum to zero, i.e. we impose the restriction $\delta=0$. This is a weak assumption given that we examine the nearby futures contract for which storage costs will be small and any convenience yield should be trivial. The above restriction implies that the fair futures price is adjusted for financing costs only as shown in equation (4.1b).

[53] One possible exception could be scalpers in futures markets.

The spot price series used in this study represent daily closing prices. The corresponding futures series are constructed from the daily closing prices on futures contracts one month prior to the expiration month. All series are in natural logarithm form. In order to account for financing costs all futures price series are adjusted to give their cash equivalent prices as described in equation (4.2), where the local market T-bill rate is used as a proxy for the risk free rate. The spot and futures series are for contemporaneous observations.

The IPE Brent crude oil futures contract is written for all months, ceases trading on the business day preceding the 15th day of the month before the delivery month, and is for cash settlement. Trades are for multiples of 1,000 barrels (42,000 US gallons), with a lower limit on price changes of one cent per barrel and no daily upper limit. Futures prices are the price at close of trading each day. Spot prices from *Datastream* are the assessment price quoted by the Independent Chemical Information Service's London Oil Report (ICIS-LOR).

The NYMEX WTI crude oil futures contracts are similarly written for all months, cease trading approximately ten days prior to the delivery month, but are deliverable. Trades are for multiples of 1,000 barrels with a lower limit on price fluctuations of one cent per barrel and a current daily upper limit of $7.5 per barrel.[54] Both markets do present a potential nonsynchronous trading problem. The IPE futures contract trades until 20:15 hours, while the spot price is quoted for close of market at 18:30

[54] The upper limits on price movements are often changed or suspended by exchanges (as occurred during the Gulf conflict). The initial price limit on WTI was $1 per barrel but has been increased, due partly to the competition offered by the IPE having no upper limit.

hours. Similarly NYMEX futures cease trading at 15.10 hours (New York time), while the spot price is quoted for 18.00 hours Texas (19.00 hours New York). These differences may bias assessments of dominance in favour of the later-closing markets. The effects of such bias cannot, however, be quantified given the nature of the data. As such we can only make the assumption that given the data's frequency, together with the relatively short period over which only one market is open, the nonsynchronous bias will be trivial.

As mentioned in Section 4.1, it is likely that in the initial period of futures trading the spot market will dominate the futures market due to relatively low trading volume in the latter market. Futures contracts for crude oil were established by the IPE in June 1988. To allow for initial thin trading, and in response to restrictions on data availability, the series considered here covers the period from April 1989 to January 1992. The whole period represents 729 daily observations. WTI crude oil futures were established by NYMEX in March 1983. In this study we consider two periods for the WTI contract. The first period examines the market in its initial years of trading. For reasons of data availability, and to allow a settling in period for the futures market, the sample period is from March 1984 to March 1988 representing 1050 daily observations. The second period corresponds to that investigated for the Brent market as detailed above.

Preliminary Results

Following Taylor (Cuthbertson, Hall and Taylor 1992), we employ the Johansen procedure (Johansen 1988) to test the hypothesis of a unit root in levels spot and futures price series. This approach uses the Johansen cointegration technique to test for cointegration in one variable, i.e. to test for integration. After first differencing, the unit root tests were reapplied. Spot and futures prices for all series under consideration were found to be I(1) in levels and I(0) in first differences. Since levels spot and futures prices are integrated of the same order they are candidates for cointegration. Results are presented in Table 4.1.

Prior to application of the Johansen Maximum Likelihood cointegration procedure we test for correct VAR order following Hall (1991). Likelihood ratio tests were carried out on VAR lengths reducing from 5 lags to one lag; test results are presented in Table 4.2. Having identified the most appropriate VAR order we proceed to test for cointegration. Cointegration tests confirm cointegration between spot and futures prices within all markets at the 5% level. This result implies the presence of an underlying ECM which can be used to model information flows between the spot and futures markets.

Table 4.1

Johansen Tests for Unit Roots and Spot/Futures Cointegration

Series		Unit Root		Cointegration
		Levels	Differences	
Brent (4/89 - 1/92)	Spot	3.880	434.583	18.378
	Futures	4.036	443.235	
WTI (3/84 - 3/88)	Spot	2.855	699.868	96.036
	Futures	2.657	746.994	
WTI (4/89 - 1/92)	Spot	5.536	485.765	111.922
	Futures	5.658	480.794	

H0: there are no cointegrating relationships.
For unit root tests the critical value at 5% = 9.243
For cointegration tests the critical value at 5% = 15.672

Table 4.2

LR Tests for Correct VAR Order

Series	Restriction on VAR Length			
	5-4	4-3	3-2	2-1
Brent (4/89 - 1/92)	4.80	46.02	14.36	155.56
WTI (3/84 - 3/88)	7.16	4.00	16.22	30.08
WTI (4/89 - 1/92)	7.10	42.04	21.96	14.78

Critical value at 5% for $\chi^2(4) = 9.49$
Brent and WTI (1989-92) are VAR(4)
WTI (1984-88) is VAR(3)

GS and GDM Point Estimate Results

The point estimates of the parameters β_s and β_f from the GS model in equations (4.4a) and (4.4b) with their associated dominance coefficients Γ are presented in Table 4.3 for each oil commodity. Comparable estimates of the parameters α_1, α_2, β_1, and β_2 from the GDM in equations (4.6a) and (4.6b) together with their dominance coefficients Γ^* are reported in Table 4.4. These results highlight some important differences between the markets studied and also provide support for the general model of dominance proposed here.

Taking the case of the GDM for Brent crude oil, the coefficients on the error-correction term (a_2 and b_2), which represent risk arbitrage activity in the futures market, are found to be numerically very small. This observation is explained by the nature of the Brent futures market. The IPE Brent futures contract is designed primarily to be an instrument for cash settlement and risk arbitrageurs are actively dissuaded from trading 'wet' barrels and are kept in the 'paper' barrel market by increasing margin requirements as the contract comes close to expiration.[55] While the error-correction terms account for little of the information transfer, the lagged difference terms (a_1 and b_1) are relatively much more important. Thus for Brent crude the price adjustments through hedging, speculation, and general arbitrage are predominant. Since such information channels are clearly so important we can place

[55] The contract does however, allow for the physical transfer of oil via exchange for physicals (EFP's).

more faith in the GDM's ability to measure the true dominance nature of the Brent market. The GDM finds spot and futures markets to share dominance equally with a ratio Γ^* of .50. The GS model conversely, by overlooking relevant information routes, suggests weak dominance by the futures market, Γ=.66.

Turning to the case of WTI crude oil we see that the error-correction terms in the GDM are the more important explanatory variables. In all cases parameters on these variables are large, in absolute terms, relative to the lagged difference terms. Again the nature of the market sheds light on these results. The NYMEX WTI crude oil contract also allows for cash settlement, but is more of market for physical delivery than its transatlantic peer, and as such arbitrage activity will remain high in the last month of trading.[56] This fact can explain why the error-correction term is important for the NYMEX contract. It also explains why the GS model and GDM give very similar measurements for dominance, (Γ=.58, Γ^*=.61 for 1984-88 and Γ=.67, Γ^*=.66 for 1989-92). In constructing the GS and GDM models we are not concerned directly with the statistical significance of the models themselves, Garbade and Silber (1983) do not present tests of the statistical specification of their model or suggest that such procedures are necessary, rather the interest in the literature is on the dominance coefficient produced from such models. In this regard the GDM mirrors accepted practice and focuses on the economic interpretation of the model rather than its statistical specification. In any case the statistical specification of the ECM is irrelevant when the output of primary interest, (the ratio of dominance) is calculated.

[56] It is estimated that about two thirds of deliveries against futures on the NYMEX are made using EFP's rather than cash settlement.

The above results attest to the usefulness of the GDM developed in this chapter. In markets where the primary information flows are captured by the error-correction term, as is the case for WTI crude, the GS model provides a good approximation of dominance, while the GDM can offer some improvements. In cases where the lagged difference terms represent the major routes through which information is transmitted between spot and futures markets, as with Brent crude, then the GDM provides a marked improvement on previous methodologies. In these latter cases the GS model can lead to false inferences being made due to incomplete specification of the dominance relationship.

Kalman Filter Results

A precise interpretation of all observed changes in dominance vis à vis information events is beyond the scope of this study, although we are able to focus upon a few key information events during the Gulf Crisis of 1990-91. As such we offer a general interpretation of dominance patterns over the long-term samples used in this study and supplement this by commenting upon a number of key events in the Gulf Crisis.

The overall picture given by the time-varying estimates of dominance is that all markets exhibit considerable change in their dominance relationships. This pattern is common to markets sampled over different time periods, locations and product type. The strong temporal nature is shown clearly by the large and often abrupt changes in both the level and direction of dominance. While futures markets are generally seen to weakly dominate spot markets, as would be expected given their lower costs, there have been a number of excursions into spot dominance.

Table 4.3

GS Point Estimates of Dominance Coefficients

$$\Delta S_t = \alpha_s + \beta_s\left[F'_{t-1} - S_{t-1}\right] + \epsilon_t^s$$

$$\Delta F'_t = \alpha_f + \beta_f\left[S_{t-1} - F'_{t-1}\right] + \epsilon_t^f$$

Series	β_s	β_f	Γ
Brent (4/89 - 1/92)	.050	.026	.66
WTI (3/84 - 3/88)	.182	.133	.58
WTI (4/89 - 1/92)	.356	.173	.67

$\Gamma = \beta s/(\beta s+\beta f)$

Table 4.4

GDM Point Estimates of Dominance Coefficients

$$\Delta S_t = a_0 + a_1 \Delta F'_{t-1} + a_2 \left[F'_{t-1} - S_{t-1} \right] + e_t^s$$

$$\Delta F'_t = b_0 + b_1 \Delta S_{t-1} + b_2 \left[S_{t-1} - F'_{t-1} \right] + e_t^f$$

Series	a_1	a_2	b_1	b_2	Γ^*
Brent (4/89 - 1/92)	.134	.051	.169	.014	.50
WTI (3/84 - 3/88)	.066	.182	.040	.120	.61
WTI (4/89 - 1/92)	.074	.340	.063	.155	.66

$\Gamma^* = (a_1+a_2)/(a_1+a_2+b_1+b_2)$

The Brent crude oil futures market, in general, has exercised weak dominance over its underlying spot market. Throughout most of the period under consideration Γ_t^* assumes a value in excess of 0.5 (see Figure 4.1), but there have been brief periods of spot dominance. While dominance was the subject of much variation from 1989 to 1991 it has remained relatively stable since then. The WTI crude oil market is observed generally to have experienced futures dominance during the early period of its existence. The period analysed here, however, begins after the first year of futures trading, and it seems likely that at some stage during that year the spot market was dominant but the futures market rapidly assumed dominance.[57] The degree of dominance by the NYMEX futures contract is seen, however, to have undergone periods of great change and occasional inversion, see Figure 4.2.

Finally, over the period 1989 to 1992 the dominance relationship for WTI crude experienced discernable periods of relative stability, see Figure 4.3. Until the end of 1990 spot markets were discovering information almost on a par with futures markets. From 1990 to 1991 futures markets exercised quite strong dominance over spot markets until an abrupt inversion marked the commencement of a stable period of spot dominance. The stable dominance of the spot market since 1991 in the WTI market contrasts with the Brent market which has experienced stable futures dominance over the same period.

[57] Schwarz and Laatsch (1991) for example, found the Major Market Index futures to assume price dominance after just ten months of trading.

The above results illustrate the differing nature of dominance between markets and commodities and also corroborate the assertion made by Schwarz and Laatsch (1991) that while futures' dominance may be the expectation, a futures market may not always maintain its leading role as the source of price discovery. Indeed it was seen in Section II 1.4 that a number of previous studies have recognised the possibility of variable strengths and directions of dominance. The reasons as to why dominance patters can change, however, is a relatively neglected area.

The most obvious candidates for explaining shifts in dominance are market structure, the size or maturity of a futures market relative to the underlying spot market, and the nature of information flowing to the market. An investigation into the maturity effect, where younger, less liquid futures markets are expected to be dominated by a relatively larger spot market cannot be undertaken in the present study due to data availability. However, the dominance response to certain information events can be studied and form the topic of the next sub-section. It is also shown there how market structure can be used to explain changes in dominance patterns.

Figure 4.1

Brent Crude Oil Dominance 1989 - 1992

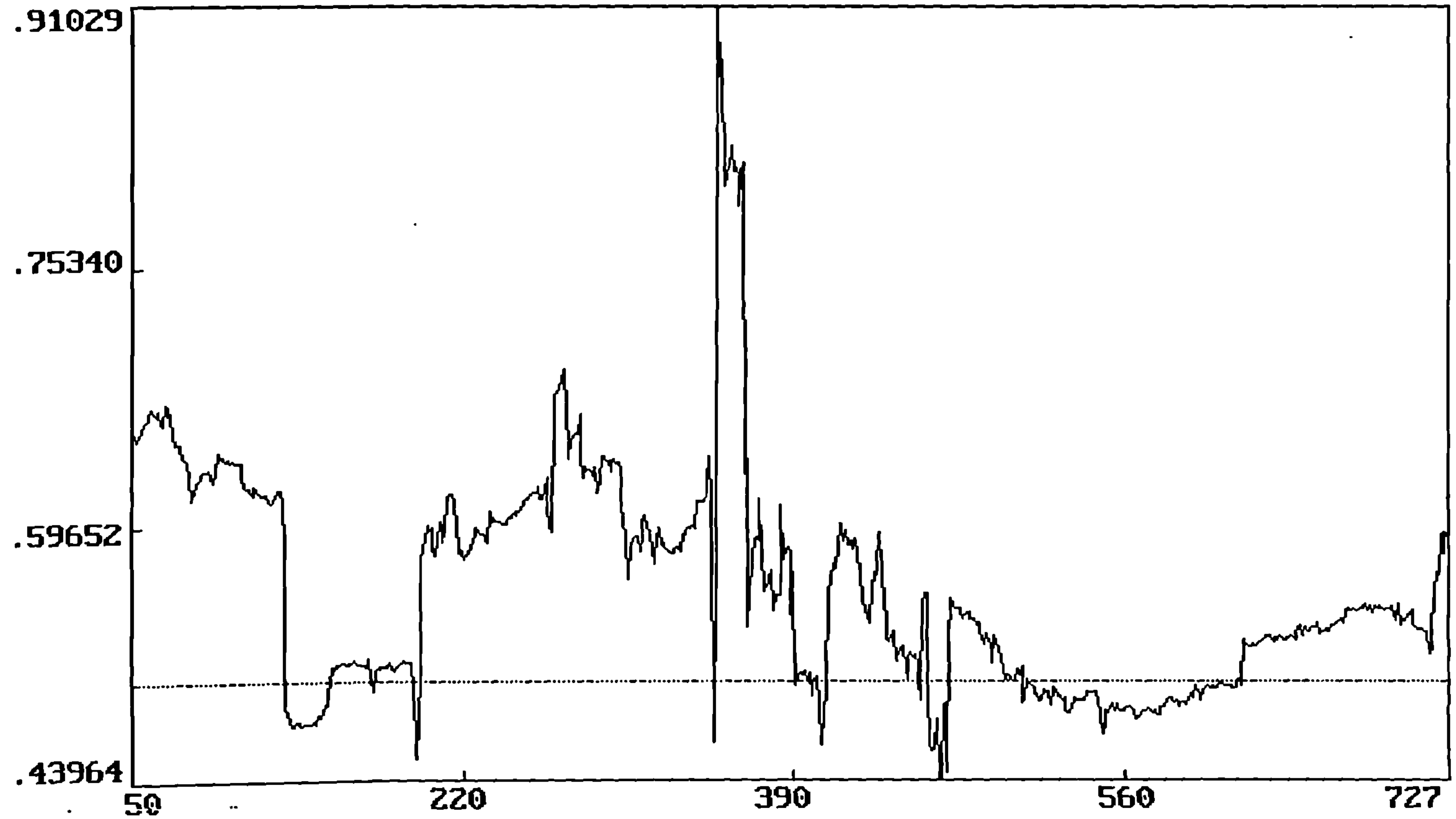


Figure 4.2

WTI Crude Oil Dominance 1984 - 1988

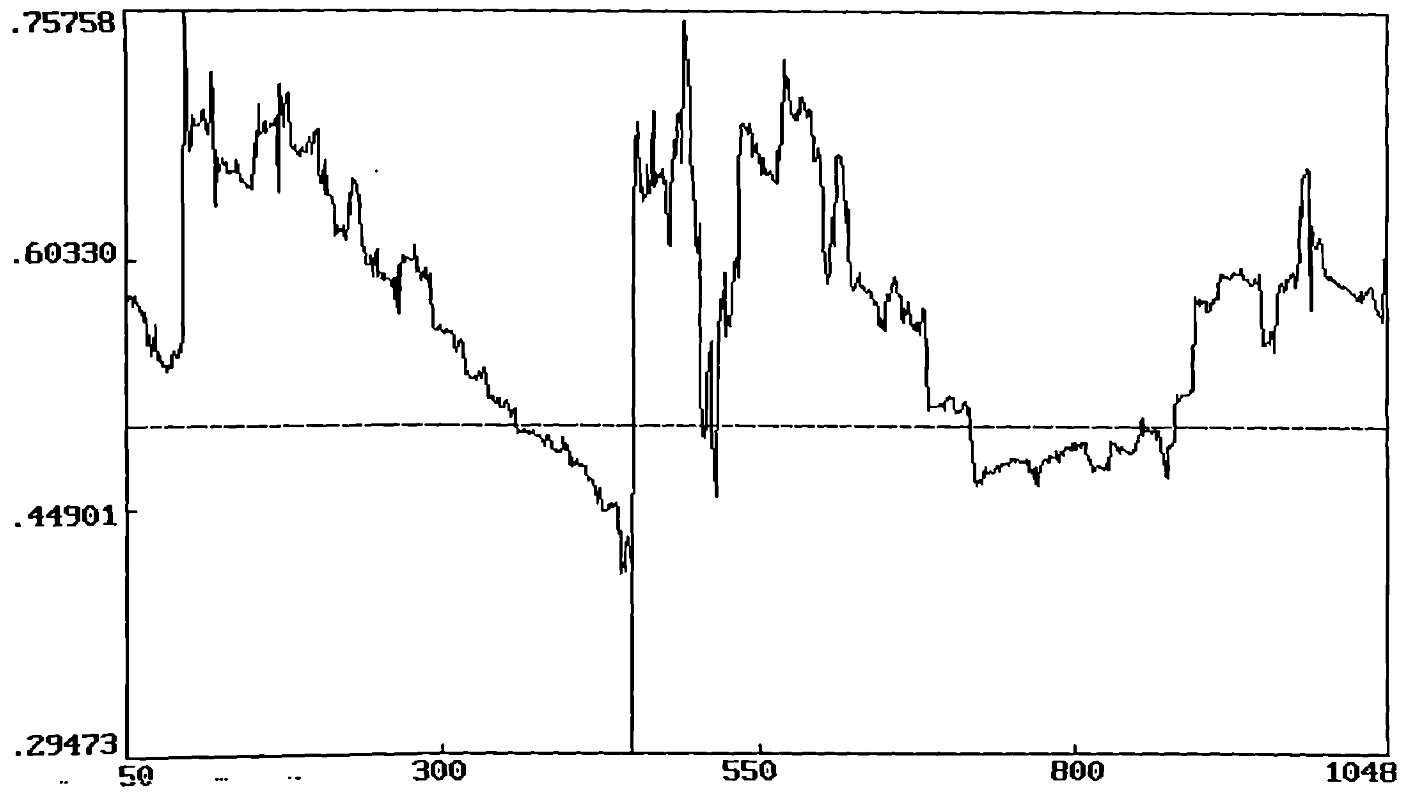
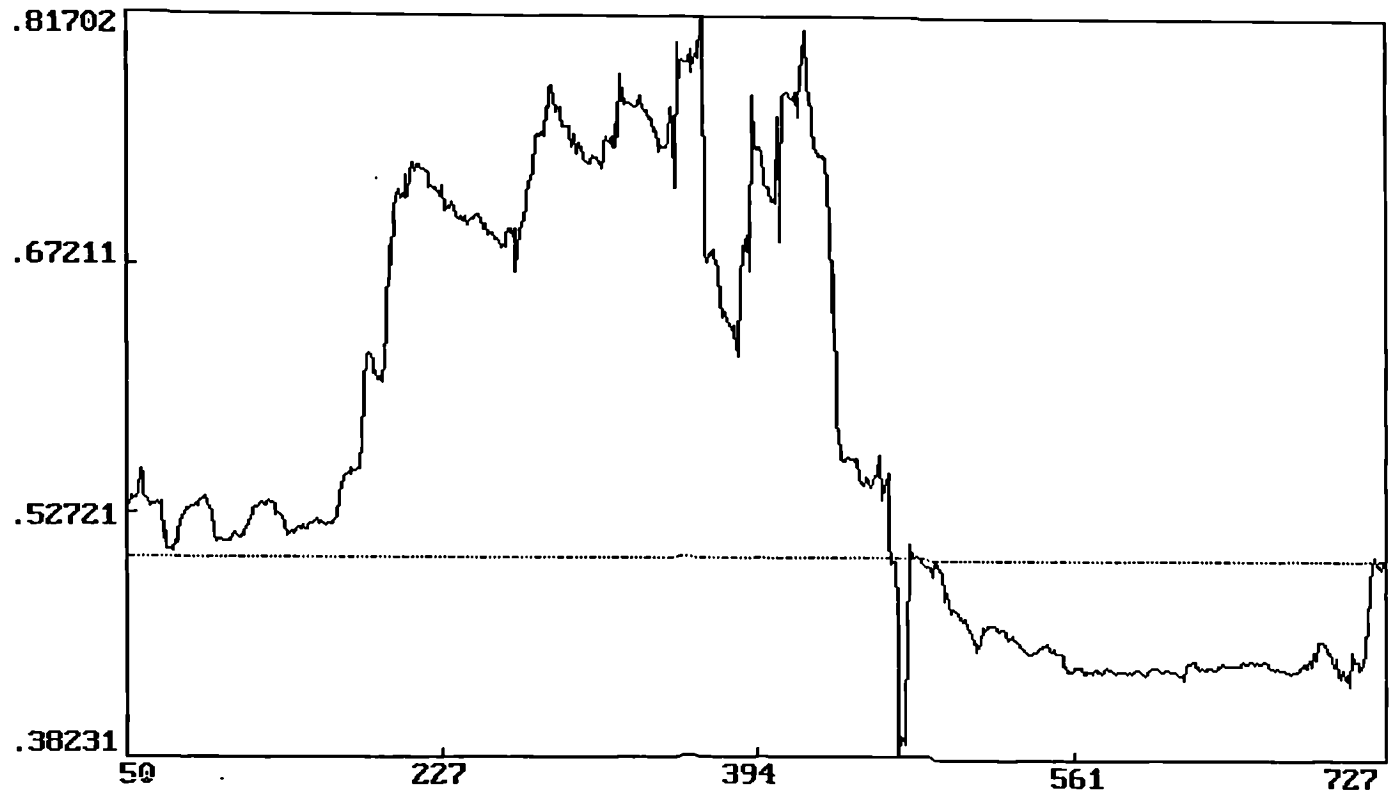


Figure 4.3

WTI Crude Oil Dominance 1989 - 1992



Dominance and the Gulf Crisis

To explore the question of dominance further we analyse the Gulf Crisis of 1990-91 since it provides a rich source of clearly identifiable, significant news events. The Gulf Crisis represents one of the most important events in the international oil market since the 1970s. Although the effects of the Crisis on oil prices were transitory, they were nonetheless very significant. The price of crude had been in decline since 1986 and stood at $15 per barrel prior to the invasion of Kuwait. During the Crisis international crude prices rose above $30p/b, returning to $18p/b with the onset of allied hostilities against Iraq. At the hight of the Crisis crude oil was trading at $41p/b. The international oil market had not experienced such a dramatic and rapid change in price since the oil price 'shocks' of 1973-74 when prices quadrupled, and 1979 when prices trebled.

The pattern of dominance is examined around four significant news events during the seven month Gulf Crisis; the invasion of Kuwait by Iraq on August 2nd 1990, the beginning of the war between the Allied Coalition and Iraq[58] on the night of January 16th/17th 1991, the commencement of the Allied ground offensive against Iraq on the night of February 23rd 1991, and the cessation of fighting on February 28th 1991.[59] these patterns are illustrated in Figures 4.4 and 4.5 where the following notation describes the above events; I corresponds to the invasion, W is the onset of the war, G marks the beginning of the ground offensive, and E the end of military combat.

[58] The war is considered to have started with the onset of the Allied bombing campaign.

[59] Since the 23rd was a Saturday the following Monday is used. On 26th February 1991 Saddam Hussein ordered Iraqi forces withdraw from Kuwait. George Bush announced the suspension of the Allied offensive from midnight (Washington time) on February 27th, February 28th in the Gulf.

Prior to the Gulf Crisis both the Brent and WTI markets were clearly characterised by futures dominance. In the five months proceeding the invasion of Kuwait, the dominance ratio for Brent assumed varying values between approximately 0.7 and 1, while the corresponding values for WTI varied between approximately 0.6 and 0.9, see Figures 4.4 and 4.5. In the five month period following the end of the Crisis both the Brent and WTI markets experienced weak dominance by the spot market reverting to weak futures dominance thereafter.

On the day of the invasion of Kuwait both markets experienced an increase in the strength of futures dominance, with the effect being more pronounced for the Brent market. This was followed by a period of very volatile dominance with an overall effect of a sharp decline in futures dominance by the time the war started; the Brent market actually moved into spot dominance shortly before this event. The commencement of hostilities between the Allied Coalition and Iraq saw the Brent market return to weak dominance by the futures market, while the WTI market moved to spot dominance for a few days, then reverted to weak futures dominance. Shortly afterwards the Allied ground offensive began but neither market seemed to react to this event with the UK market exhibiting a state of almost symmetric feedback (Γ^* very close to 0.5), while the WTI market remained relatively unchanged with weak spot dominance. The official cessation of hostilities also had no discernable effect on either market. In the following we offer some possible explanations for these observed changes in dominance patterns.

The uncertainty surrounding the initial stages of the Gulf Crisis saw interest in futures rise as traders sought protection. During August 1990 the IPE witnessed 600,000 contracts being traded for Brent crude, 40% more than in July of that year. The experience was shared by NYMEX where there were 2.7 million crude oil contracts traded in August, 35% more than in the preceding month. While the volume of trade in futures markets during August 1990 indicates a high degree of liquidity, trade in the spot markets during the period was reportedly much weaker. The invasion of Kuwait prompted fears that the supply of oil from Kuwait and possibly Saudi Arabia could be lost. For the first week after the invasion spot markets for crude oil were very illiquid as those who owned physical stocks of oil were reluctant to sell. This lack of liquidity would make spot trades infrequent and so lead to more discrete price changes in that market. This in turn gives a plausible explanation for the increase in futures dominance since those markets became more liquid in both relative and absolute terms. After the first week spot markets became less reluctant to trade as can be observed with the decline in futures dominance exhibited in Figures 4.4 and 4.5. This event corresponds to the arrival of US troops in Saudi Arabia on 9th August and the condemnation of the Iraqi invasion by the Arab heads of state the following day. These events would have considerably eased worries over the future supply of oil from both Kuwait and Saudi Arabia. Thus, after the initial shock of the invasion which saw futures markets assuming strong dominance due to a lack of spot trading, the spot market began to reassert a price discovering function as agents began to trade more freely on the spot markets.

From the date of the invasion until the onset of the Allied Coalition's air offensive against Iraq the dominance pattern of both the WTI and Brent markets showed a decline in futures' dominance to an almost symmetric dominance relationship; in fact the Brent market moved into a position of weak spot dominance. The beginning of the bombing campaign against Baghdad, however, witnessed changes to the dominance relationships. In the case of the UK market the air offensive coincided with a switch of dominance from spot to futures markets, while the reverse occurred in the US. To find explanations for these events we may turn to the nature of futures contracts traded on the NYMEX and IPE markets. The bombing campaign coincided with the expiration of the nearby futures contract on both the NYMEX and IPE futures exchanges. As mentioned above, these contracts differ in that while the NYMEX futures contract is deliverable, the IPE contract is for cash settlement. The bombing of Baghdad saw crude oil prices fall significantly on hopes of an early end to the Conflict. Given the fall in oil prices we could expect speculators in the US with short futures positions to buy oil on the spot market so as to deliver against their futures commitments. Since volume data is unavailable for oil spot markets this supposition cannot be given direct support. It is clear, however, that there was no significant move into the futures market with trading volume being largely unaffected. The IPE futures market, by comparison, experienced significantly greater trading as volume doubled in response to the event. Since the IPE contract is for cash settlement, speculators will have moved into the futures market in order to offset their current positions given the fall in oil price and expectations of a speedy conclusion to the war. Thus, one possible explanation for the relative shifts in dominance is the actions of informed market agents moving from one trading arena to another.

The third main event of the Conflict to be investigated here is the start of the Allied ground offensive against Iraq. The experience of the UK and US markets for crude oil was a shared lack of response, in terms of dominance patterns at least, to this event. At this stage of the Conflict, however, the fear of and Iraqi offensive into Saudi Arabia, or even their continued annexation of Kuwait had been removed. As such while the news events were significant in their own right, they did not cause market agents to adjust their main arena for trading i.e. speculators moving into the spot market, or to alter their normal trading patterns i.e. producers increasing their hedging activity. Moreover, the event occurred on a Saturday, and since it became clear very soon afterwards that the ground campaign had met little opposition, by the time markets opened the following Monday the Conflict was all but over.

The cessation of hostilities also had no apparent effect upon dominance patterns for either of the markets considered. This would suggest that the order for Iraqi forces to withdraw, and the announcement by the US that the Allied offensive would be suspended did not cause a significant shift in the behaviour of traders in the spot and futures markets. By this time the markets had already settled into a period of relatively stable dominance with both the UK and US markets discovering information on a roughly equal basis between their spot and futures markets. This new steady state appears to have been the most permanent effect on oil market dominance of the whole Conflict. Of late, however, oil futures markets in both the UK and US have begun to exhibit weak dominance over their respective spot markets.

Figure 4.4

Brent Dominance January 1990 - September 1991

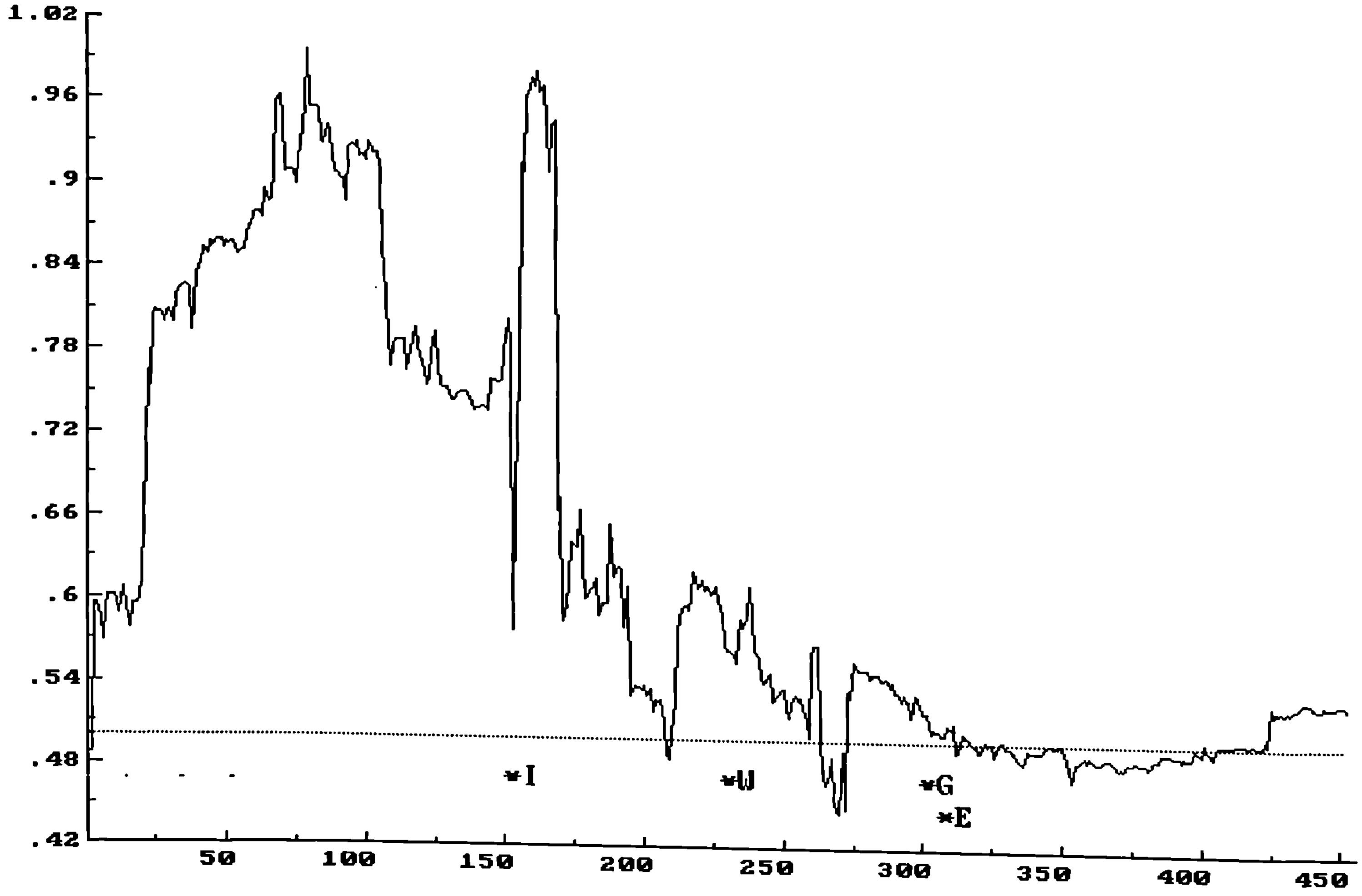
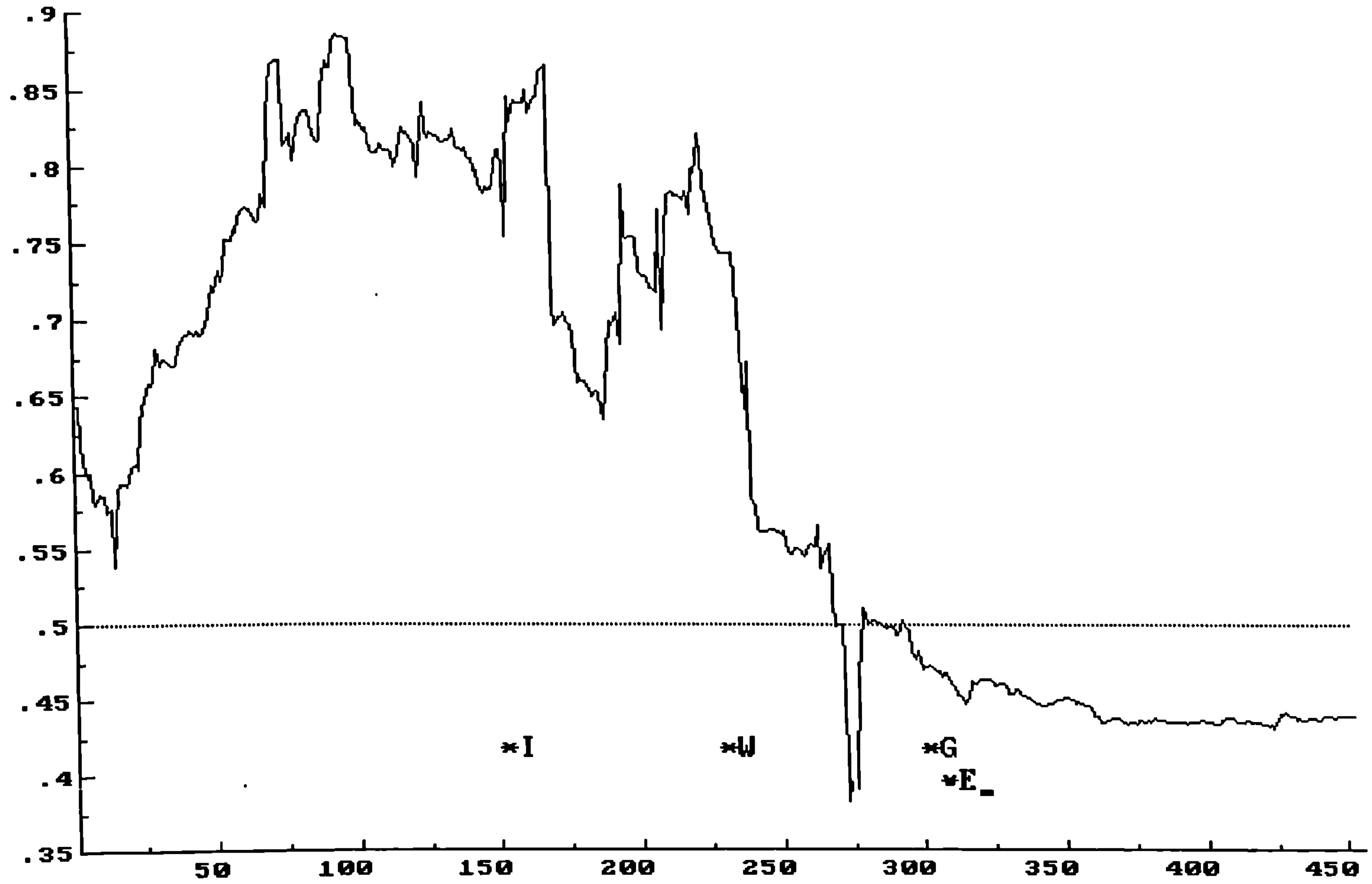


Figure 4.5

WTI Dominance January 1990 - September 1991



4.7 SUMMARY AND CONCLUSIONS

The aim of this investigation was to re-examine price dominance relationships between spot and futures markets. This task was undertaken on both a theoretical and empirical level. On a theoretical level we present a general model of dominance which synthesises the two main methodologies previously used in testing dominance relationships. This is achieved using a framework of cointegration and error-correction models. The general model presented here is an improvement on previous methodologies in that it accounts for all channels through which information is transmitted between spot and futures markets. This is seen to be a significant improvement for markets in which hedging, speculation and general arbitrage activity 'discovers' information, and a noticeable improvement in markets where risk arbitrage accounts for information discovery. Thus, we confirm that different markets experience different dominance patterns due to information flowing through different channels. This is clearly the case for the Brent and WTI crude oil markets which experience their main information transfers through very different routes.

On an empirical level we depart from the traditional use of point estimation in calculating dominance: point estimation is a practice which we show can yield unreliable results. Given the link between dominance and the transmission of information between markets we can expect the character of dominance to change as both the nature of information and market relationships change. As such we use recursive estimation to establish the dynamic nature of dominance, and the Kalman Filter to model its time-varying properties. From the time-varying estimates we see that all markets exhibit asymmetric-feedback relationships. On the whole futures markets are seen to weakly dominate spot markets. Dominance is confirmed to have strong temporal characteristics and so cannot be assumed to remain constant, with both the level and direction of dominance being the subject of much change. This point highlights the dangers of using point estimates and arbitrary sample divisions when estimating dominance and supports the use of time-varying parameter models in order to properly model dominance.

Using a generalised model of dominance within a time-varying parameter framework we find dominance to exhibit very strong temporal characteristics. In both the UK and US markets the overall nature of dominance is found to have undergone significant changes. Turning to the Gulf Conflict, it is observed from Figures 4.4 and 4.5 that while futures markets dominated spot markets prior to the Gulf Conflict, the relationship has been largely reversed since then. Naturally, given the transitory nature of dominance, these results do not (and cannot) imply a permanent change in relationship between oil spot and futures markets. They do, however, indicate a relative improvement to information responses in the spot markets, presumably as a result of their greater use driven by the events of the Gulf Conflict.[60]

The relationship between spot and futures prices has long been the subject of debate. Spot and futures prices cannot behave independently of one another in a well-functioning market, since they are linked by arbitrage forces, see Garbade and Silber

[60] There is no evidence to suggest that futures markets have become less efficient since the Gulf Conflict; this being the alternative explanation for the spot market's increased (relative) dominance.

(1983). Thus, if spot and futures prices diverge by more than the cost of carry (adjusted for any convenience yield) then the potential to earn riskless profits will drive prices back to their efficient relative values. Naturally, given the presence of transaction costs, this relationship will not strictly hold in practical terms.

Evidence from this study shows that, for the most part, futures prices tend to move in response to information before the response of the spot price. The tendency for futures markets to be 'first off the mark' is attributed to their trading characteristics which allow their prices to register new information before the same response in the underlying actual. Care should be exercised, however, since the observation that a change in a futures price is followed by a like change in the spot price, is not *necessarily* indicative of a causal relationship. As elaborated by Granger (1986), spot and futures prices represent prices for the same commodity; at contract maturity the prices are equal, prior to maturity they are inextricably linked. New information should then affect both prices in the same fashion. One further point of interest is that it will not always be the futures market which is first to discover information. We have observed conditions where spot prices 'lead' price changes in futures markets. As such the relationship between the two markets is characterised as one of mutual interaction, as the market in the best position to register new information will signal that information to its partner via price changes.

CHAPTER 5

THE JOINT DYNAMICS OF VOLUME AND PRICE VARIABILITY IN OIL FUTURES MARKETS

5.1 INTRODUCTION

When new information arrives on the market, agents react by trading until prices reach a revised, post-information equilibrium. Trade will occur both in response to the arrival of new information on the asset's value itself and as risk averse agents engage in hedge rebalancing trades.[61] Hedgers are motivated to trade in futures contracts to stabilise their future income flows or costs, with their volume of trading determined by the their expectations of future spot (and futures) price movements. Similarly speculators take an interest in futures contracts based upon their expectations of futures' price variability. The above process of revision results in price change and trading volume, and since they are both driven by the same directing variable, namely the flow of information, it is expected that they will exhibit positive correlation. The precise nature of the relationship between price variability and volume has not, however, found consensus.

The purpose of this chapter is to investigate the dynamic relationship between trading volume and price variability in oil futures markets on an empirical level with the aim of addressing four main areas of such relations. In the first instance the investigation examines the general relationship between the trading in futures markets and the price

[61] It should be noted that as traders switch from nearby contract to next-nearby contract this will create volume that is not related to the arrival of new information. In terms of this investigation the construction of the data series is such that such volume is not considered.

variability of futures contracts. This allows an assessment of the efficiency of futures in themselves, as opposed to their efficiency in relation to spot markets which was the subject of the previous two chapters. Essentially the investigation tests whether the predicted contemporaneous volume-price-variability relation holds over a lagged relation. The implication of a lagged relation being found is that lagged volume could potentially be used to predict future price variability, thus violating informational efficiency in oil futures markets. A second question is whether the level of trading volume associated with a price rise is different to that associated with a price fall, i.e. does market activity differ with the direction of price movements. Theoretical work provided by Karpoff (1987) suggests that futures markets should not exhibit asymmetric trading volume responses to the sign of price changes, and this assertion is tested in this chapter. Moreover, this question offers a test of futures markets' efficiency in that a symmetric relation is indicative of a market where agents have linear unbiased responses to information.

A third area of interest is whether the size of the futures market affects the volume-price-variability relationship, and to explore this question we consider two comparisons; the large market against the small market, and the initial market phase and mature market phase. The final hypothesis to be investigated in this chapter is whether the price-volume relationship changes during identifiable events. In investigating this issue the study essentially addresses the question as to whether the rate of flow of information affects the relationship. The hypothesis forwarded in this regard is that the relationship is stronger at times when information flow is most volatile, and for this purpose we use specific events during the Gulf crisis.

Increased volume in futures may lead to increased price variability in futures and so invite demands for their regulation. While the question of the effect of futures volatility on spot price volatility has been addressed in Chapter 2, this chapter concentrates upon futures volatility itself. The question of regulation depends upon the precise effects of the positive relationship between volume and volatility. Increased trading volume causing increased price variability may suggest a need for the imposition of regulatory restriction on speculation. Conversely, if it is increased price variability which leads to increased volume then this would signify a responsive, liquid and efficient market which may be harmed by further regulation.

The role of trading volume in markets has been the subject of a considerable amount of research, which commonly points towards a strong positive relationship between volume and price variability. On a theoretical level explanations for the relation have revolved around two main theories: the sequential information model and the mixture of distributions hypothesis. These models are described in the next section. The reason as to why such a relation exists has, however, only recently received attention on a theoretical basis in the form of a model furnished by Blume, Easley and O'Hara (1994), which describes the informational role of volume. This model is distinct from others in that it studies volume in itself, demonstrating how volume can affect market behaviour, rather than simply describing the correlation of volume with price.[62] On an applied level investigation has been largely based upon identifying empirical regularities between volume and price change. While studies have examined both spot

[62] A similar point is raised by Gallant *et al* (1992) who remark that much of the work in this field has centred around data-based empirical work, and has failed to properly analyse the information structure.

and futures markets the vast majority have concentrated on spot financial assets.

This investigation is intended to provide evidence for the volume-price-variability relationship for commodity futures, and specifically oil futures which have not previously been tested for such relationships. In doing so we offer a number of contributions to the current literature. First we consider the symmetry of the volume-volatility relation both as a test of market behaviour and efficiency. Second, we consider the effects of market size and maturity on the volume-volatility relation. In brief the relation is found to be symmetric, while market size is seen to have little effect upon the relation other than that which could be attributed to increased liquidity. The main body of this investigation however, deals with the temporal relation between price variability and trading volume, which is found to be contemporaneous. In undertaking this analysis we offer a further contribution by using a system of equations to model volume and volatility simultaneously; a practice largely absent in the current literature.

The chapter proceeds as follows. Section 5.2 presents a discussion of the theoretical issues of the volume-volatility relation, while Section 5.3 presents some empirical issues on the subject and explains the methodology of preliminary tests. Sections 5.4 and 5.5 deal with the main methodologies adopted by the investigation and describe their application to tests of the volume-volatility relation. Section 5.6 describes the data used and presents preliminary empirical results in accordance with the tests detailed in Section 5.3. Empirical results for the main methodologies are presented and discussed in Section 5.7, with Section 5.8 providing concluding remarks to the chapter.

The previous section noted two leading models which provide theoretical explanations for the observed correlation between price variability and trading volume; the mixture of distributions hypothesis due to Clark (1973), Epps and Epps (1976), and Harris (1987), and the sequential information model of Copeland (1976) and Smirlock & Starks (1984). Before considering these explanations it is constructive to illustrate the way in which price change and trading volume relate to each other and to the flow of information. This is accomplished by explaining the underlying market process for price change and trading volume in a fashion similar to that provided by Epps (1975) and Epps and Epps (1976). Begin from a situation of equilibrium and assume that traders have expectations of the future value of an asset. Assume that in time period t that expectation differs from its value in period t-1. In this situation the trader will have excess demand or supply at their t-1 price. This disequilibrium is assumed to result from the inflow of new information regarding the asset which causes a discrepancy between the market price and the trader's "null" price.[63] The arrival of new information is expected to affect different traders in different ways such that trading will occur until markets clear at a new equilibrium price. In this way information generates both trading volume and price change.

The essential practical difference between the sequential information model and mixture of distributions model for explaining this association rests on the speed with which the new equilibrium is attained. The sequential model allows a number of

[63] The "null" price is defined as that price at which the trader's excess demand or supply is zero.

incomplete equilibria to be reached before the final equilibrium is found, while the mixture of distributions model assumes that the final equilibrium is immediately attained. The remainder of this section is given to explaining the two models in greater detail.

The Sequential Information Model.

The sequential information model (SIM) due to Copeland (1976) is based upon the key assumption that traders in a market receive new information pertinent to an asset in a sequential, random fashion. From an initial position of equilibrium where all traders possess the same set of information, news arrives on the market and traders will shift their demand or supply accordingly. The information signal is not received by all traders simultaneously but is observed by each individual in turn whose trade in response to the signal represents one of a series of incomplete equilibria. Once all traders have received the information signal a final market equilibrium is established where traders observe the same information set. Traders who are as yet uninformed are assumed not to infer the new signal from informed traders' actions. This notion conflicts with recent work on "mimetic contagion" (see Topol (1991)), where it is suggested that agents accept that they face an incomplete information set and so infer signals from the trading activity of others. In fact Karpoff (1987) cites as a main criticism of the SIM its prohibition of traders learning from the market price of informed traders.

The SIM assumes a market consisting of N traders of whom k are optimists and r pessimists as defined by their trading response to an information signal. As a consequence of agents being sequentially informed there will be N-k-r uninformed traders at any one time. In the model's framework the price adjustment between the initial and final market equilibria is known with certainty, but the path of price adjustment traced by successive incomplete equilibria and the trading volume which they generate will be random variables. Thus, successive price adjustments, and the successive and total volume figures will be dictated by the pattern by which traders are informed. Indeed since optimists and pessimists disagree about the implications of an information signal there can be numerous possible paths through which the intermediate equilibria could travel before a market equilibrium is re-established. Since each possible path of information dispersion may have a different amount of trading volume associated with it, total volume will be random.

The total trading volume associated with a price change is, therefore, a random variable whose value can be determined using probability theory; expected volume is a weighted average of the total volumes generated by each possible path of information dispersion. Since the aim of this study is to asses the relation between price change and volume rather than explain how a given amount of trading volume arises from price changes, a technical presentation of Copeland's probability model will not detain us. The key interest here in the SIM is its implication for the volume-price-variability relation, and on this point the model has a number of important implications. The primary implication for this study is that a sequential reaction to information suggests that asset price volatility and/or trading volume will be potentially forecastable with knowledge of each other. Tests of the SIM support the commonly observed positive correlation between absolute price changes and trading volume.

The Mixture of Distributions Hypothesis.

The mixture of distributions hypothesis (MDH) provides a model which implies stochastic dependence between volume and price returns. Specifically, the conditional variance of a price increment from one period to the next is a function of the trading volume related to that price change. The MDH models furnished by Clark and by Epps and Epps offer different yet complementary explanations for the positive price variability-volume relationship. Clark (1973) posits that futures price volatility and volume traded should be positively related, and that according to the theoretical framework suggested by the mixture of distributions hypothesis this relationship is a positive function of the directing (or mixing) variable, the rate of information arrival. Daily price variance is considered to be a random variable representing the sum of individual price changes within the day, and trading volume is positively related to the number of within-day price changes. The outcome of such trading is, therefore, the contemporaneous change of both prices and volume.

The variant of the MDH furnished by Epps and Epps (1976) requires all investors to receive information simultaneously, while the Clark and Harris versions of the hypothesis can be mutually consistent with sequential information model in that while they imply simultaneous information dissemination, it is not a requirement. At the limit, of course, as the successive equilibria described by the sequential model become closer together, the price reactions to information will approach a state equivalent to simultaneity.

The following provides an exposition of the MDH as provided by Harris (1987). The MDH for the joint distribution of price change and volume is based upon two initial assumptions. First that the joint distribution of price changes and trading volume is bivariate normal conditional upon the arrival of information variable, n_t. This can be illustrated as follows;

$$\Delta P_t \sim N(\mu_p n_t, \sigma_p^2 n_t \,|\, n_t) \tag{5.1}$$

$$V_t \sim N(\mu_v n_t, \sigma_v^2 n_t \,|\, n_t)$$

where ΔP_t represents price returns, V_t is trading volume and the subscripts p and v relate to price returns and volume respectively. Second the number of information events occurring in any one day (n_t), which determines the overall daily price return ΔP_t, is random. This latter assumption implies that price changes will be subordinate to n_t giving,

$$\Delta P_t = \sum_{i=1}^{n} \delta_{it} \tag{5.2}$$

where δ_{it} is the *i*th price increment generated by the directing variable, or stochastic rate of information arrival, n_t. Thus, since price change and trading volume are assumed to respond to each information event, their total daily quantities will be the cumulation of responses to the n_t information events. From the bivariate normal distribution the conditional variance-covariance matrix will be proportional to the conditioning variable n_t and since n_t is stochastic the variance-covariance matrix will be heteroskedastic as is shown by the main diagonal in equation (5.3);

$$Cov(\Delta P_t, V_t | n_t) = \begin{bmatrix} \sigma^2 n_1 & \cdot & \cdots & 0 \\ \cdot & \sigma^2 n_2 & \cdots & 0 \\ \cdot & \cdot & \cdot & \cdot \\ 0 & \cdot & \cdots & \sigma^2 n_m \end{bmatrix} \tag{5.3}$$

The unconditional distribution of price change and volume will differ from the conditional variance since it is a mixed distribution, namely a weighted average of the conditional distribution and the distribution of n_t. The implication of the MDH is that prices and volume will have a joint response to information due to their common distribution. Intuitively this means that all traders will simultaneously view the excess supply and demand, and the price implications of the arrival of a new piece of information. As such the shift to a new equilibrium will be immediate, and the partial equilibria of the sequential information model will never be visited.

The Information Content of Volume.

Blume, Easley and O'Hara (1994) provide a model which departs from previous theoretical models in this field of research, and provides new dimensions to its study, by describing the informational role of trading volume in markets. The model is based upon the primary assumption that traders receive pricing signals of differing precision or quality. In this framework, the notion is forwarded that volume provides information on the precision and dispersion of information signals which price alone does not. As such the model relates volume, information and price movements, and in so doing entertains the possibility that volume could contain information about price movements. The point of interest to us here is that the information content of volume implied by the model suggests a degree of inefficient pricing in that volume statistics can improve forecasts of future price movements.

To begin, markets are assumed to contain noise whose source is the (deficient) precision of information contained in prices. Since price alone does not permit traders to observe the information signal, and so the true value of the asset, volume may yield sufficient additional information for that signal to be observed. Given price, volume is assumed to convey information about the price signal's precision, which is used in conjunction with price to make inferences about the mean information signal i.e. the true asset value.[64] Thus, since volume may provide additional information regarding the quality of information, traders will condition their price expectations on volume as well as price.

It is through the model that Blume *et al* demonstrate that the widely accepted view that trading volume is driven by the flow of information need not necessarily hold, such that low volume may be as indicative of new information as high volume. The key to this assertion rests with the notion of information precision, in that it is not just information *per se* but also the quality of information which dictates trading volume. Thus, if low quality information signals are received by market agents then traders place little confidence in them and so will be reluctant to trade. This is best illustrated by the limit position where the information signals are of such poor quality that trading volume is zero. In this way volume can indicate the precision of an information signal.

[64] The mean information signal should converge to the asset's true value plus a common error term.

Another dimension to the model is that it allows the dispersion of information to play a role in the volume-volatility relation. By stipulating a market consisting of informed and uninformed traders, the model proposes that the more widely an information signal (of a given precision) is spread amongst market agents, the lower will be the trading volume. This arises from the assumption that informed traders will only trade with uninformed traders. As with the question of information precision therefore, the relation between information and volume is shown to be complex with the need to take a broader set of factors into consideration. The implications of this model are examined in Section 5.6.

5.3 Empirical Issues

This section looks at the empirical regularities which have been commonly documented in studies of the relation between volume and price change. Investigations have considered both price change *per se* and absolute price changes with respect to volume movements. In line with these investigations, and to provide an initial understanding of the price-volume relation it is beneficial to examine these empirical regularities. Having described the methodologies used to test for such empirical findings, the investigation proceeds in the next two sections to explain the GARCH and generalised method of moments (GMM) methodologies used for direct tests of the volume-volatility relation.

Volume and Price Change Per Se

It has commonly been expected that large trading volumes will be associated with an increase in price, while a fall in price corresponds to low trading volume.[65] Such phenomena suggest that the direction of price change rather than its dispersion will be related to the magnitude of trading volume. Findings in support of this relation have been reported only for spot equity and bond markets, and results tend to weak. Moreover, these findings conflict with the theoretical view derived from the MDH (explained in the next sub-section) that price change and volume will be positively correlated. Karpoff (1987) provides an explanation for this observation based upon asymmetric costs between long and short positions for spot assets. Due to their relative costliness there is a restricted demand for short sales in spot markets. Since short sales are made by traders whose information leads them to expect a price fall, relative trading volume will be lower for price falls than price rises given such cost asymmetries.[66] Futures markets conversely do not face short sale restrictions and the costs of taking long or short positions are symmetric. Empirical evidence for futures markets is consistent with this hypothesis since it finds no significant relation between the direction of price change and trading volume.

Previous empirical work notwithstanding, this study tests for such a relationship in order to establish whether the price-volume relationship is indeed symmetric for oil futures, and that the dispersion of price changes is positively related to volume. The

[65] This is supported on a casual basis with the observation that trading tends to be higher in bull markets than bear markets.

[66] In this regard any violation of the MDH is attributed to market frictions rather than inconsistencies in the relation of information to volume and price change.

investigation is carried out on two levels. In the first case we undertake casual observation of the volume-price-change relation by considering plots of price changes against volume. More rigorous testing follows by taking the series of daily (log) price changes and associated trading volume for each market and separating those series into two sub-series of negative and positive price changes respectively. The study then proceeds to examine the volume statistics associated with each sub-series in order to assess whether there is symmetry in volume responses to the direction of price change; this is achieved by testing for significant differences between the mean and dispersion of the volume sub-series.

Volume and Absolute Price Change

Consensus has it that generally there will be a positive correlation between the volume of trade and the magnitude of (absolute) price changes, i.e. high volume indicates large price changes (in either direction) and vice-versa. This finding is based on the common reactions of both price volatility and volume to information flows, and can be explained by the MDH. The positive correlation between (absolute) price changes and trading volume is described in terms of the MDH by Harris (1987) due to the likelihood that both variables will be large when their common directing variable is large, and be small when it is small. This relation is subjected to casual testing in this study by plotting volume against absolute price changes as a way of inferring positive correlation between the variables. The correlation coefficient between absolute price changes and trading volume is also examined in order to add some statistical support to these initial findings.

Market Size Effect

One area of interest identified by Karpoff (1987) as meriting further research is the effect of market size on the volume-volatility relationship. This area can be divided into two areas; the first comparing the relationship in markets whose primary distinction is size, and the second investigating changes in the nature of the relationship as a market grows. The second possible effect of size was suggested by Tauchen and Pitts (1983) which implies that as the number of traders grows, the volume of trade will increase and price variability will decline, i.e. volatility declines as the market becomes larger. This suggestion does not conflict with the general empirical finding of a positive relation between price variability and trading volume, but must be interpreted carefully. While at first glance the positive variability-volume relationship and the liquidity argument outlined above appear contradictory, they do in fact affect markets at different levels. One should not, therefore, confuse the message that illiquid markets can lead to prices exhibiting substantial departures from fundamentals, with that that trading volumes and price changes are both responses to information flows. At the general level one can find support for the idea that greater trading volume *per se* will lead to lower price fluctuations. This arises since liquid markets are less prone to prices being pushed away from fundamentals due to insufficient trading levels. Once markets are liquid, however, daily trading intensity differentials will reflect, and may indeed be symptomatic of the rate of information arrival.

The level of trading volume may be viewed as a measure of the liquidity in markets, and so indicate the effect of liquidity upon volume-price-variability relations. It is noted that the oil markets considered in this study are all highly liquid and so any such comparisons are based upon the relative liquidity between the markets. The hypothesis to be tested here is that price volatility is higher when the level of liquidity (trading volume) is low. Moreover, if it is found that illiquid markets are volatile, then this has an obvious implication for the effects of regulations which aim to restrict trading. If markets are over regulated then trading limits will limit the amount of price-responsive volume thus leading to more volatile prices. This revisits some of the issues raised in the Chapter 2.

In order to analyse the possible influence of market size on the volume-volatility relation this study considers three market samples: the IPE futures market is compared with the relatively larger NYMEX market to give what might be termed a cross-sectional comparison;[67] in addition the NYMEX market is compared at both early and more recent phases in its existence in order to provide a growth or 'maturity' comparison.

The Rate of Information Flow Effect

In his review Karpoff (1987) further identifies the properties of the rate information arrival as an issue which requires further investigation. Since information is assumed to drive prices and volume, Karpoff suggests that the volume-volatility relationship will be strongest at times when the flow of information is most volatile. This can be tested for oil by investigating the relationship around the events of the 1990/91 Gulf

[67] As shown in Table 1.1 the WTI futures market is approximately six time the size of the Brent market as measured by trading volume.

Conflict which represents a period significant news events and volatile prices. The response of oil futures to the Gulf Conflict is analysed in Chapter 4, and while the objective there is not to test the volatility of prices as such, it is clear that they were substantially more variable in that period that in other less eventful periods, see Section 4.6. This period faced a combination of greater uncertainty in oil prices and more attention being paid to those prices by the market. The aim of this investigation is to ascertain how the volume-volatility relation reacted in this period. The analysis is undertaken through a comparison of GMM models estimated for the Gulf Conflict with those estimated for a sample controlling for that event.

5.4 GARCH Model for Volume and Volatility

The majority of previous studies have used constructed measures of volatility and so suffer from the same measurement problems encountered by studies of the volatility effects of futures on spot markets, namely the estimation of volatility.[68] More recent studies have adopted GARCH models to assess volatility, notably Lamoureux and Lastrapes (1990), and Najand and Yung (1991). Moreover, since volume and volatility are assumed to be driven by information flows, the rate and size of which are stochastic, changes in volume and volatility will also change over time. In fact this point is raised by Harris (1987) who suggests that since variations in the directing variable may be random rather than uniform, price variances too may randomly

[68] This is given more detailed discussion in Chapter 2. For a review of the most common constructed measures of volatility used in this field see Board and Sutcliffe (1991).

change through time. Heteroskedasticity in price returns is in fact a consequence of them being generated from a mixture of distributions. This observation lends clear support for the use of GARCH models for investigating the volume-volatility issue.

The main motivation for the use of GARCH models for investigating volume-volatility relations is provided by Lamoureux and Lastrapes (1990), who describe a framework where the MDH can be expressed as a GARCH model whose specification derives from serial correlation in the directing variable; the rate of information arrival. This practice finds intuitive support by noting that where information arrives onto the market in 'clusters', this leads to the clustering commonly observed in asset returns which can be characterised with a GARCH process.[69] The following provides an exposition of the Lamoureux and Lastrapes framework which begins with the assumption from the MDH that the unexpected price change in a day, ε_t, will be the sum of a number of intraday price equilibria as given in equation (5.2') which is presented again below for convenience with notation slightly changed for consistency.

$$\epsilon_t = \sum_{i=1}^{n} \delta_{it} \tag{5.2'}$$

where δ_{it} and n_t are as previously defined. The model proposes that if δ_i is i.i.d with mean zero and variance σ^2 and if n_t is large then,

$$\epsilon_t | n_t \sim N(0, \sigma^2 n_t) \tag{5.4}$$

[69] See Figures 2.2 and 2.3 for an example of such volatility clustering.

The association between GARCH and the MDH is elucidated by presenting a GARCH model as a manifestation of time dependence in the rate of evolution of intraday price changes driven by n_t. Thus, the daily quantity of information inflow is determined to be serially correlated as exhibited by the autoregressive representation;

$$n_t = \alpha_0 + \alpha_1 \sum_{i=1}^{m} n_{t-i} + u_t \tag{5.5}$$

where innovations in the directing variable persist as dictated by the structure of equation (5.5). The Lamoureux and Lastrapes model proceeds by defining a variance term,

$$\Omega_t = E(\epsilon_t^2 \mid n_t) = \sigma^2 n_t \tag{5.6}$$

which is substituted into an MA reparameterisation of equation (5.5) to give an expression for the variance analogous to that of a GARCH process;

$$\Omega_t = \sigma^2 \alpha_0 + \alpha_i \sum_{i=1}^{m} \Omega_{t-i} + \sigma^2 u_t \tag{5.7}$$

Since the rate of information flow is not directly observable, trading volume is proposed as a proxy for the directing variable. This practice is consistent with Copeland's SIM and the model provided by Epps and Epps (1976) but may, it is noted, be inappropriate if prices and volume are a joint function of information arrival. The assumption that volume can be used as the directing variable consigns it to be exogenous to the volatility equation, and it is entered into the GARCH representation as follows;

$$\Delta F_t = \alpha + \epsilon_t \qquad \epsilon_t = N(0,h_t) \tag{5.8}$$

$$h_t = a_0 + \sum_{i=1}^{q} a_i \epsilon_{t-i}^2 + \sum_{j=1}^{p} b_j h_{t-j} + \gamma V_t \tag{5.9}$$

where ΔF_t is the futures price return in period t
V_t is trading volume with the MDH supported when $\gamma > 0$.

If prices and volume are jointly determined, or if information is not exogenous, then equation (5.9) may be subject to some simultaneity bias. Najand and Yung (1991), adopt the model in equation (5.9) but find volume to be endogenous, and so avoid the problems of specification bias by treating it as predetermined with the following model variation:[70]

$$h_t = a_0 + \sum_{i=1}^{q} a_i \epsilon_{t-i}^2 + \sum_{j=1}^{p} b_j h_{t-j} + \gamma V_{t-1} \tag{5.10}$$

This study also considers two additional variations of the GARCH model in order to explore the possibilities that the volume-volatility relation is nonlinear, or that changes in volume have explanatory power. This is approached by including a squared volume term, and a first difference of volume respectively in the GARCH model used here. Tests for the specification of the GARCH process indicate that a GARCH(1,1) model explains oil futures' volatility adequately and is adopted for this investigation.

While GARCH analysis may be useful for the purpose of examining the role of

[70] It is common practice to treat lagged endogenous variables as being exogenous to the model.

volume in volatility it does suffer from a number of short-comings. In the first place it considers the relationship from one side only; the effect of volume on volatility. This relates to the second issue where the introduction of volume into the GARCH equation is believed here to be more a test of whether volume represents a proxy for information than a test of the volume-volatility relation. Finally, the use of contemporaneous volume still leaves open the question of simultaneity bias which needs to be addressed. In light of these factors this study progresses from GARCH analysis to model volume and volatility as a system of simultaneous equations. Given the heteroskedasticity in the joint density function predicted by the MDH, an appropriate technique for this analysis is the generalised method of moments (GMM) as proposed by Hansen (1982).

5.5 GMM Model for Volume and Volatility

As stated above, the relation between volume and price-variability has been generally addressed on an applied level where empirical regularities between volume and price change are identified. In this investigation we propose the use of an instrumental variable (IV) estimator as a GMM estimator. In modelling the volume-volatility relation we face the dual problem of a simultaneity bias leading to an inconsistent estimator, together with heteroskedasticity in the estimator's covariance matrix as predicted by the MDH. The IV approach is particularly suited to this subject since it allows us to model contemporaneous volume and price-variability, thus avoiding problems of simultaneity bias noted by previous studies. In addition, the use of a

GMM framework produces heteroskedasticity-consistent estimates by 'correcting' the covariance matrix of the (consistent) IV estimator.

In light of the contemporaneous relation between volume and volatility we may estimate a system of equations using IV analysis. To describe this procedure we begin with a simple single equation model as follows;

$$y = X\beta + u \tag{5.11}$$

where the estimator of β is inconsistent due to some of the variables in X being correlated with the errors; $cov(X_i, u_i) \neq 0$. To derive a consistent estimator we must find a set of variables or *instruments*, Z, which are correlated with the explanatory variables in X but are uncorrelated with the errors.[71] Regressing the variables in X on those in Z generates predicted values of X known as instrumental variables, X'. These predicted values are then used in the above equation to calculate a consistent estimator of β. While X' will give a consistent estimate of β, the covariance matrix of the estimator will be inefficient. This is particularly true in this case given the presence of heteroskedasticity as dictated by the MDH. This problem is, however, automatically accounted for by the GMM procedure.

Turning our attention to the volume and volatility relation, the following system of identified structural equations can be specified;

[71] For time-series data it is common to use lagged (predetermined) values of X as instruments; the presence of predetermined variables in the model suggests that they are correlated with the endogenous variables, while the fact that they are predetermined implies that they are not correlated with the error term.

$$
\begin{aligned}
V_t &= \alpha_0 + \alpha_1 h_t + \beta_1 V_{t-1} + \epsilon_t \\
h_t &= \gamma_0 + \gamma_1 V_t + \delta_1 h_{t-1} + u_t
\end{aligned} \tag{5.12}
$$

where h_t represents the volatility variable,
V_t is the volume variable.

It is evident from equation (5.12) that the parameters α_1 and γ_1 are on endogenous variables, a fact which guarantees that OLS estimates of the system parameters will be inconsistent. Conversely, the parameters β_1 and δ_1 are attached to predetermined variables. Restricting attention to the first equation, for convenience only, the predetermined variable V_{t-1} is independent of the error term ε, thus $\mathrm{cov}(V_{t-1},\varepsilon) = 0$. However, h_t is not independent of the error term and so $\mathrm{cov}(h_t,\varepsilon) \neq 0$. For the system as a whole we require instrumental variables for h_t and V_t and can use lagged values of volume and volatility for that purpose.

When we have a unique set of estimates for the parameters in the structural equation system, we say that the system is exactly identified. When multiple estimates are obtained the system of structural equations is overidentified, while the failure to obtain estimates of the parameters implies an unidentified model. The reduced form of equation (5.12) included up to five lags of both variables for each market considered, and identification is tested using the test provided by Hansen (1982).

5.6 Data and Preliminary Analysis

The data set comprises daily closing prices for a roll-over of nearby futures contracts written on Brent crude and WTI crude from the IPE and NYMEX respectively, together with their corresponding daily trading volumes. The nearby futures contract is selected since it attracts the greatest amount of trading activity. Futures returns series are calculated as the first difference of the log of closing prices. The sample used for both markets is from the January 1990 contract to the June 1994 contract. Due to a number of unavailable observations for volume data, the series yield 1120 observations for the Brent contract and 1062 observations for the WTI contract. A third sample was also included covering WTI futures from the January 1984 contract to the June 1988 contract representing 1109 observations. The latter sample is included so as to allow comparisons of the volume-price variability relation over time. In order to investigate the volume-price-variability relation during concentrated a period of significant news events a sub-sample of the data is defined for the time of the Gulf Conflict of 1990/91. The sub-sample is from 1st August 1990 (the invasion of Kuwait) to 28th February 1991 .(the official cessation of hostilities), which gives 147 observations.

As noted in Chapter 1 the amount of trading volume for oil futures has experienced rapid growth, and as such we expect the volume series used in this analysis to exhibit an upward trend. The tendency is illustrated for the case of Brent futures over the period 1990 to 1994 in Figure 5.1 in which there is a discernable upward trend in the data. In order to properly assess the relationship between volume and price variability it is desirable to remove such trends from the volume series prior to empirical analysis. The preferred method adopted here for detrending the volume series is that provided by Gallant, Rossini and Tauchen (1992) since it preserves the units of measure in detrended data that are used in the unadjusted data. This property facilitates the interpretation of results and avoids the use of negative volume figures associated with other methods of detrending. The following presents an outline of the detrending process used in this analysis. To perform their data adjustment Gallant *et al* (1992) utilise a two-stage process where systematic effects in the data are first removed from the mean and then from the variance. This is achieved by specifying a set of adjustment variables to capture the systematic effects. For the present purpose of detrending volume, the variables are limited to a linear time trend t and a quadratic trend variable t^2. The adjustment to the mean is achieved by regressing the logarithm of daily trading volume V_t on the set of adjustment variables:

$$V_t = \beta_0 + \beta_1 t + \beta_2 t^2 + u_t \tag{5.13}$$

The residuals from the mean equation are then standardised using the following variance equation;

$$\log(u_t^2) + \alpha_0 + \alpha_1 t + \alpha_2 t^2 + \epsilon_t \tag{5.14}$$

From the variance equation the detrended log volume series is derived from the following transformation where l_t are the fitted values from the variance equation, and where a and b are selected such that the mean and variance of the log volume (V_t) and detrended log volume (V_t') are the same. Thus we have,

$$V_t' = a + b(u_t/\exp(l_t/2)) \tag{5.15}$$

The detrended volume series for Brent crude futures computed in the above fashion are presented in Figure 5.2. For all three samples used in the study the unadjusted volume series confirm the linear and quadratic time trends to be statistically significant at the 5% level. The same time trends were globally rejected for the detrended series.

In order to gain an initial view of the nature of the three samples under consideration, Table 5.1 provides some summary statistics. As can be seen from these results, the IPE market has a lower mean trading volume than that for NYMEX over the same period as would be expected given the relative ages and importance of the two futures contracts. We further note the casual observation that the larger the mean trading volume the lower tends to be the variability in volume, an observation that could be explained in terms of market liquidity since larger (more mature) markets will face fewer occasions of very low or insufficient trading volume. For all market samples the correlation of volume with price change is considerably lower than that with absolute price change, a fact which corroborates the expectation that in futures markets it is not the direction but the dispersion of price changes which affect volume. In addition we observe that the correlation between trading volume and a measure of volatility (generated from a GARCH equation run on futures' returns) is as strong as the correlation of volume with absolute price changes; suggesting that a GARCH volatility measure can be substituted for absolute price change for examining volume-volatility relations.

Figure 5.1

Unadjusted Logarithm of IPE Brent Futures Trading Volume

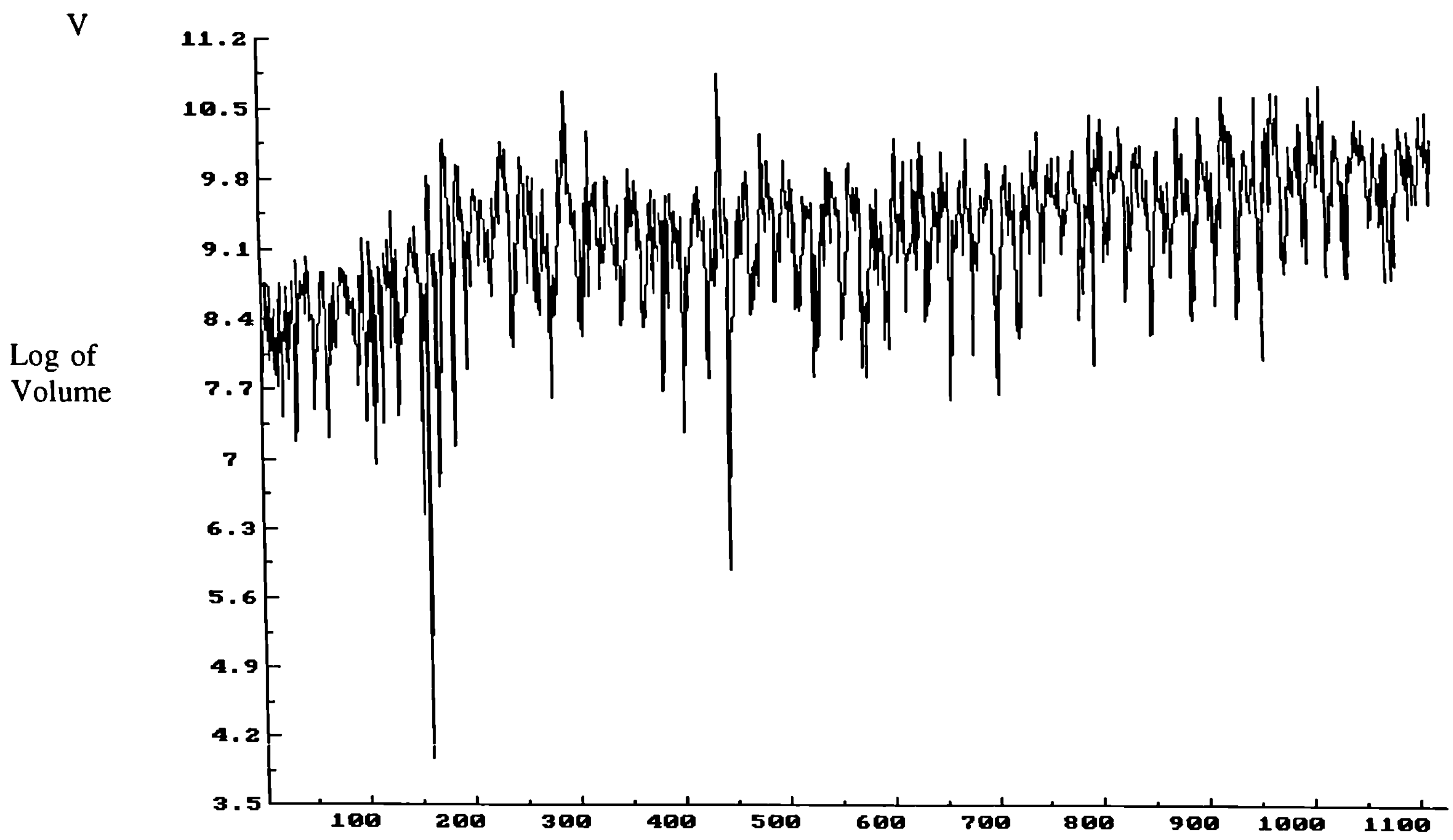


Figure 5.2

Detrended Logarithm of IPE Brent Futures Trading Volume

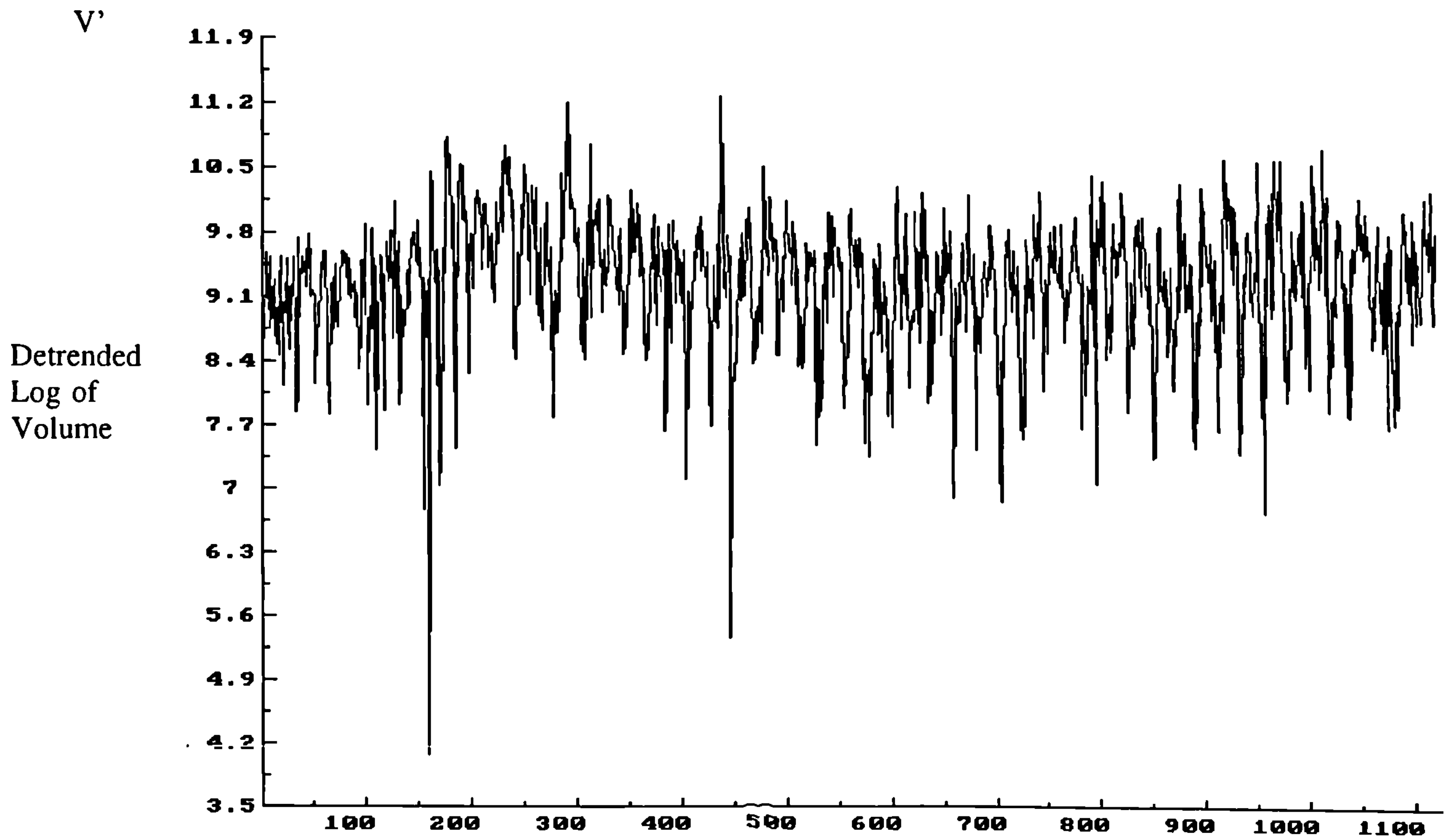


Table 5.1

Summary Statistics and Correlations for Volatility and Volume Series

	IPE Brent 1990-94			NYMEX WTI 1984-88			NYMEX WTI 1990-94		
	Volume	ΔF_t	$\lvert\Delta F_t\rvert$	Volume	ΔF_t	$\lvert\Delta F_t\rvert$	Volume	ΔF_t	$\lvert\Delta F_t\rvert$
Mean	9.284	.161E-3	.0138	8.883	-.470E-3	.0127	10.3704	.157E-3	.0144
St.dev	.6979	.0219	.0169	.8646	.0207	.0164	.4935	.0161	.0216
Corr V'	-	.0172	.2691	-	.0178	.1845	-	.0253	.2236
Corr (h,V')	.2642	-	-	.1429	-	-	.2335	-	-

The columns labelled ΔF_t and $\lvert\Delta F_t\rvert$ are for price returns and absolute price returns respectively. Volume (V') is detrended log volume and the Corr V' row shows the correlation coefficient for volume and the price returns series. The row 'Corr (h,V') presents the correlation coefficient for volume and a measure of volatility (h) generated from a GARCH specification of the price returns series.

Volume and Price Change Per Se

To provide a preliminary analysis of the volume-price-variability relation we consider Figures 5.3 to 5.5 which provide scatterplots of price returns against classes of trading volume for Brent and the two periods of WTI futures respectively. Each class consists of a range of trading volumes, as an illustrative example the volume class 4 represents all values on the logarithm of trading volumes greater than 4.00 and less than 5.00. Volume classes are plotted in order of increasing magnitude, and are utilised to clarify the nature of the relation. In each example we observe a clear relation between the magnitude of price movements and the amount of trading volume, as the dispersion of the distribution of price returns increases with volume. This finding is consistent with the theoretical propositions of Karpoff (1987) and Harris (1987) detailed in Section 5.3, and the empirical findings of Gallant *et al* (1992), who adopt a broadly similar exposition of the volume-price-variability relation.

Figures 5.6 to 5.8 essentially reproduce the results illustrated in Figures 5.3 to 5.5 but provide actual volume figures rather than volume classes, thus offering a more detailed view of the relationship between trading volume and price variability. The figures generally comply with proposition of Blume *et al* (1994), that volume is strictly convex in price. In their theoretical model of volume and information Blume *et al* further suggest that the precision and dispersion of information determine the shape of the relation between price variability and volume. In their model a high precision of information yields a V-shape relation, with the V-shape becoming more sharply defined as the precision of information increases.

Figure 5.3

Plot of Price Returns against Log Volume Class (Brent 1990-94)

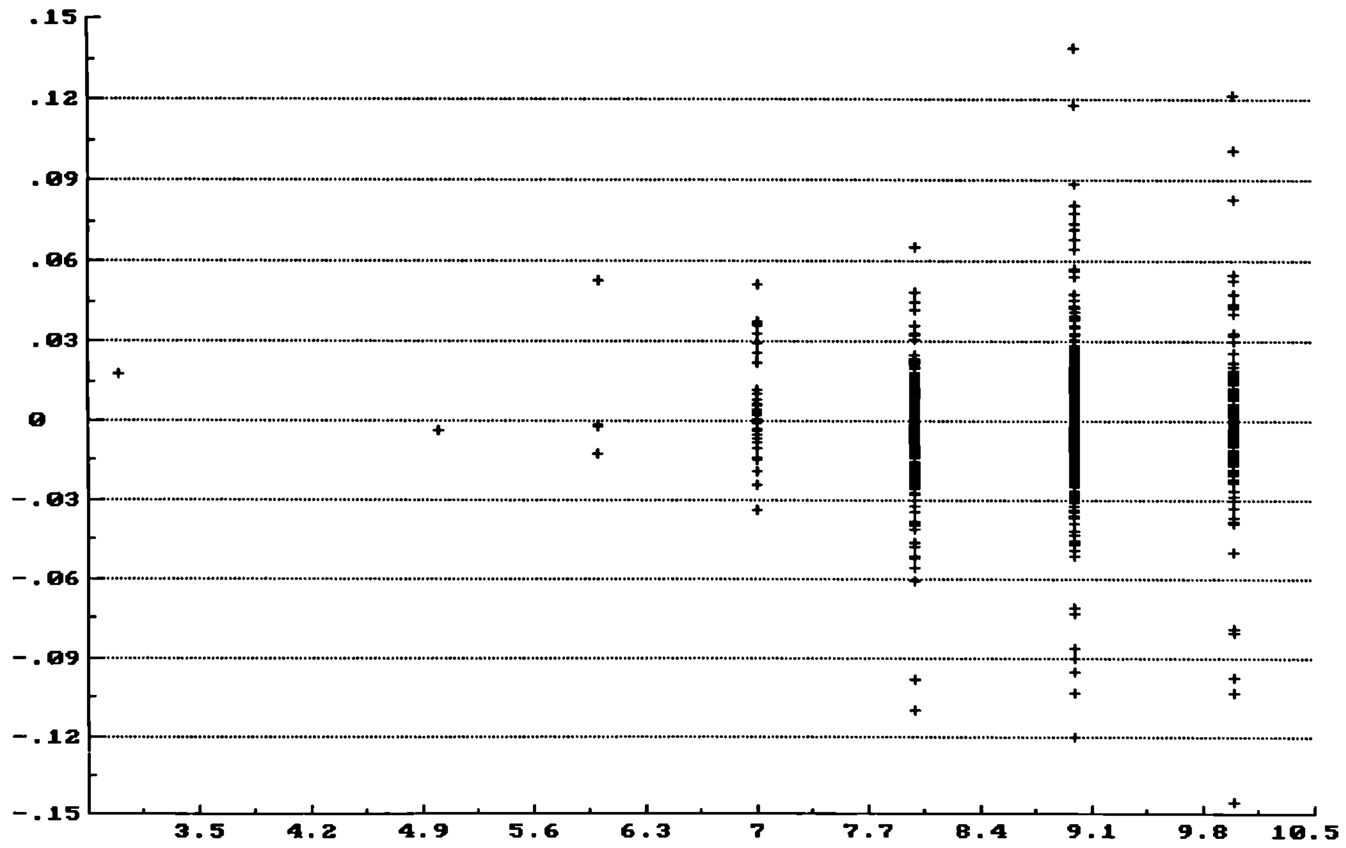


Figure 5.4

Plot of Price Returns against Log Volume Class (WTI 1990-94)

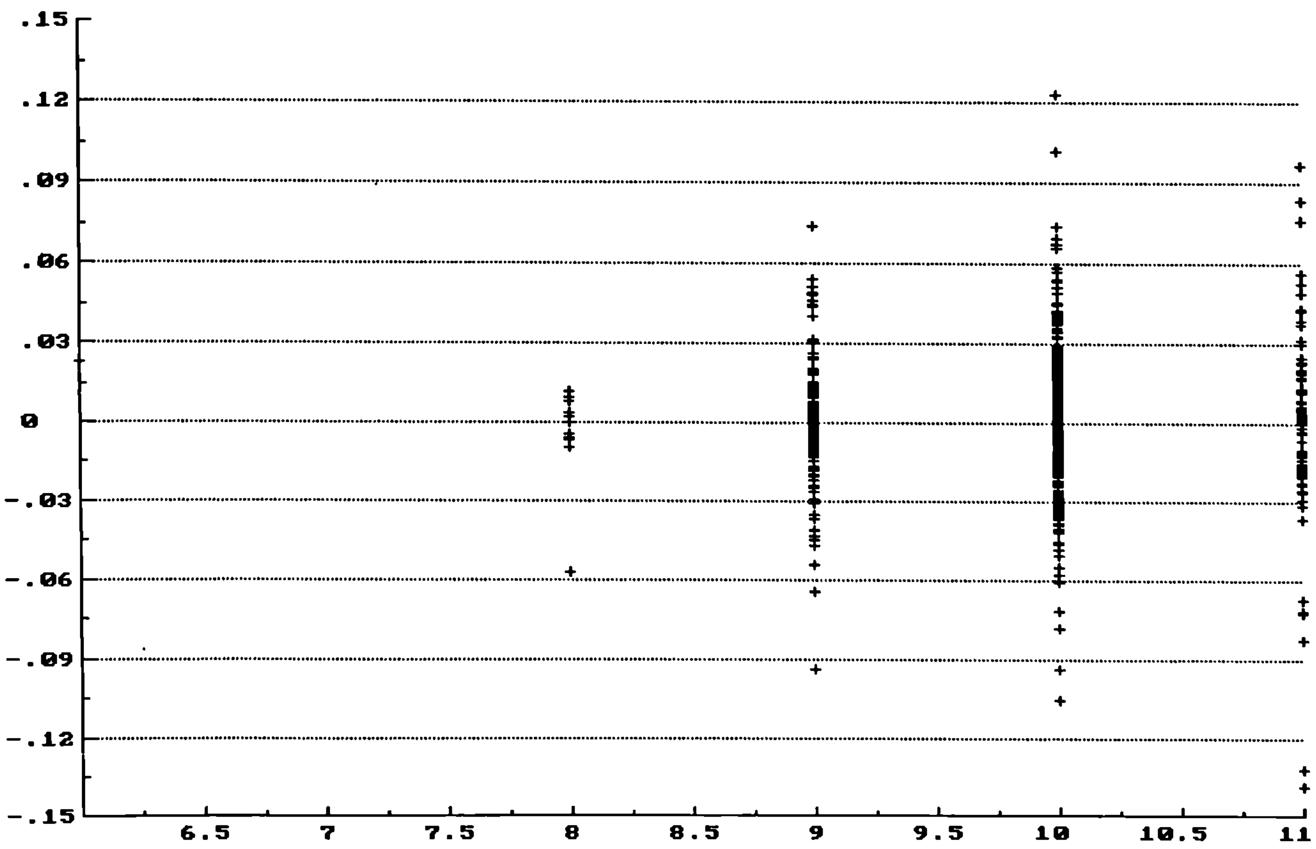


Figure 5.5

Plot of Price Returns against Log Volume Class (WTI 1984-98)

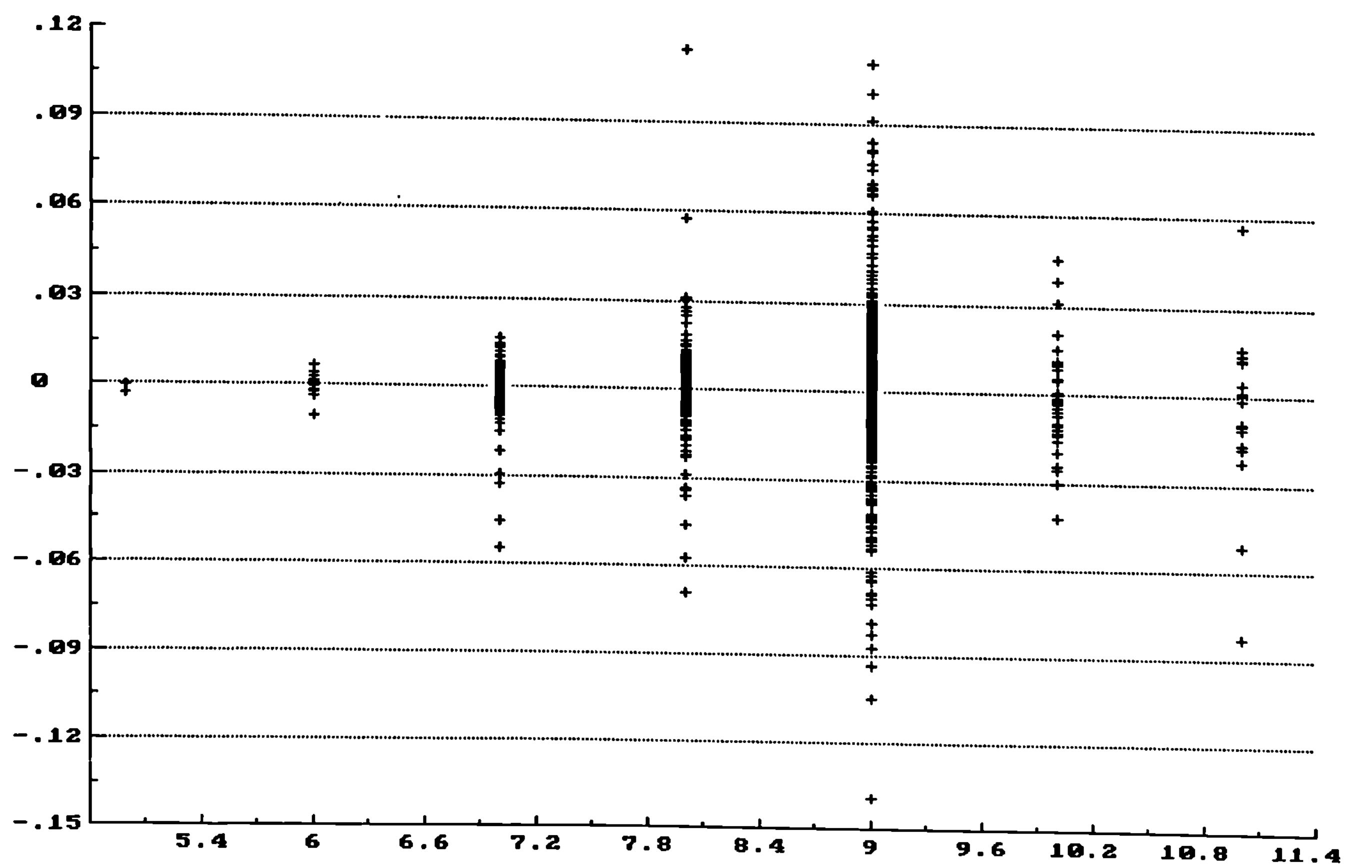


Figure 5.6

Plot of Detrended Log Volume against Price Returns (Brent 1990-94)

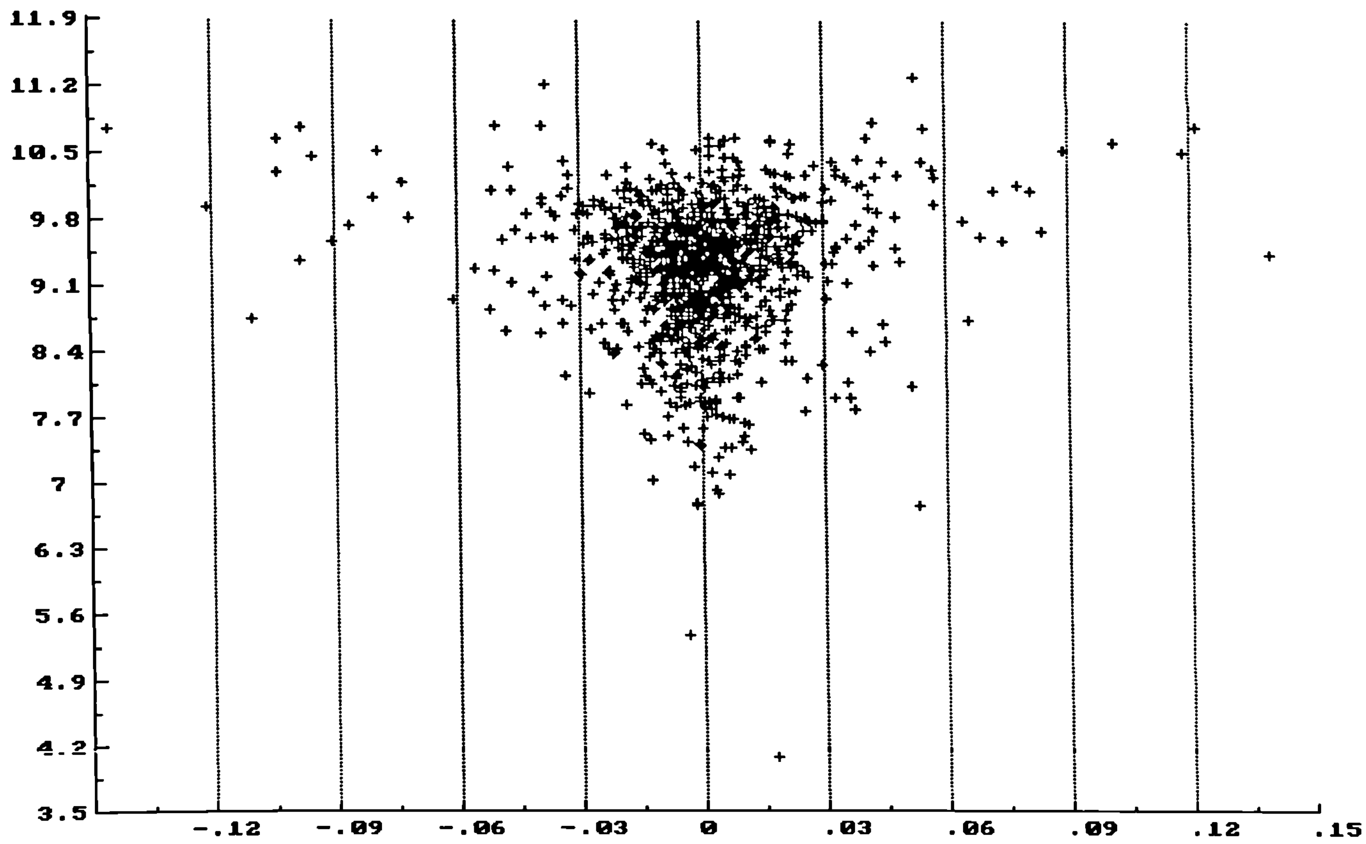


Figure 5.7

Plot of Detrended Log Volume against Price Returns (WTI 1990-94)

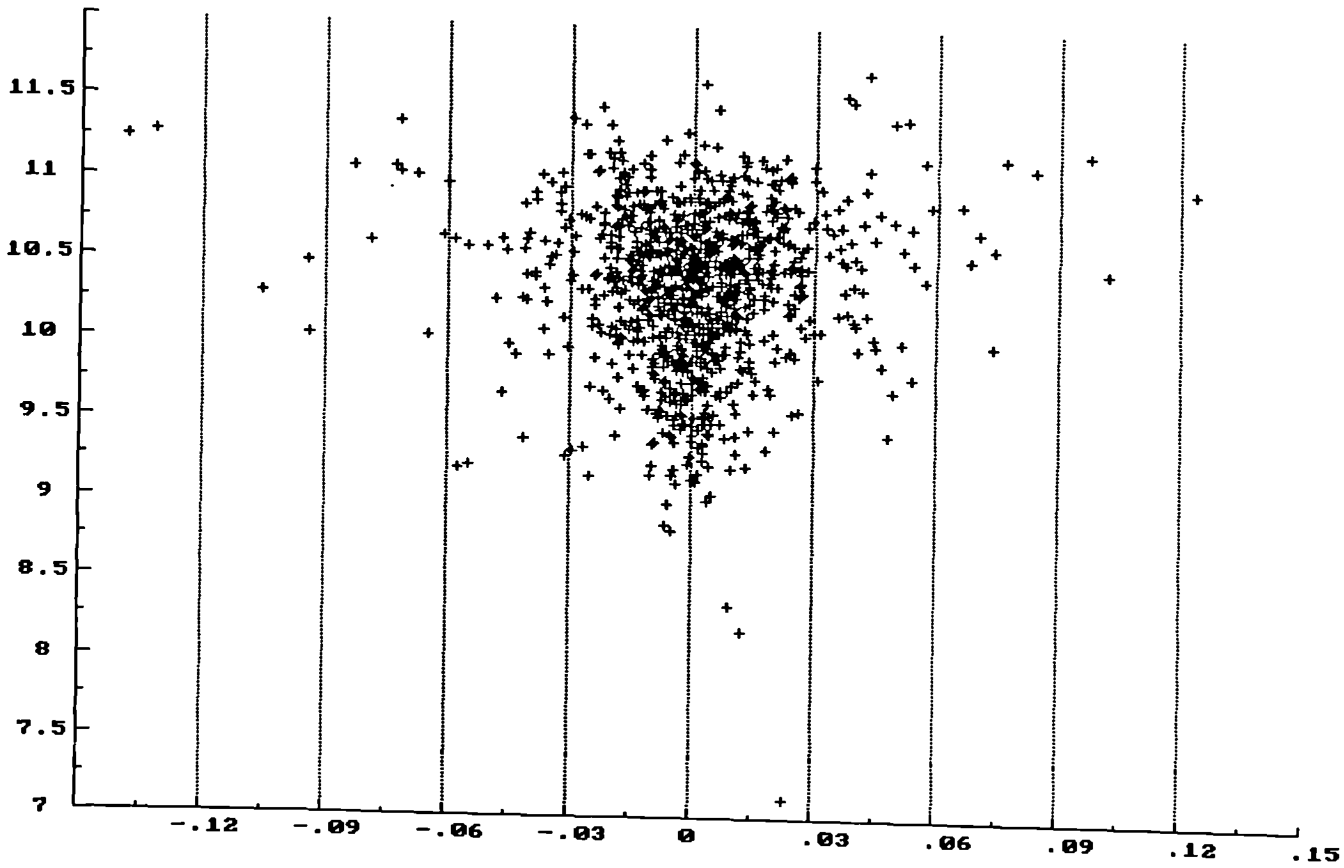
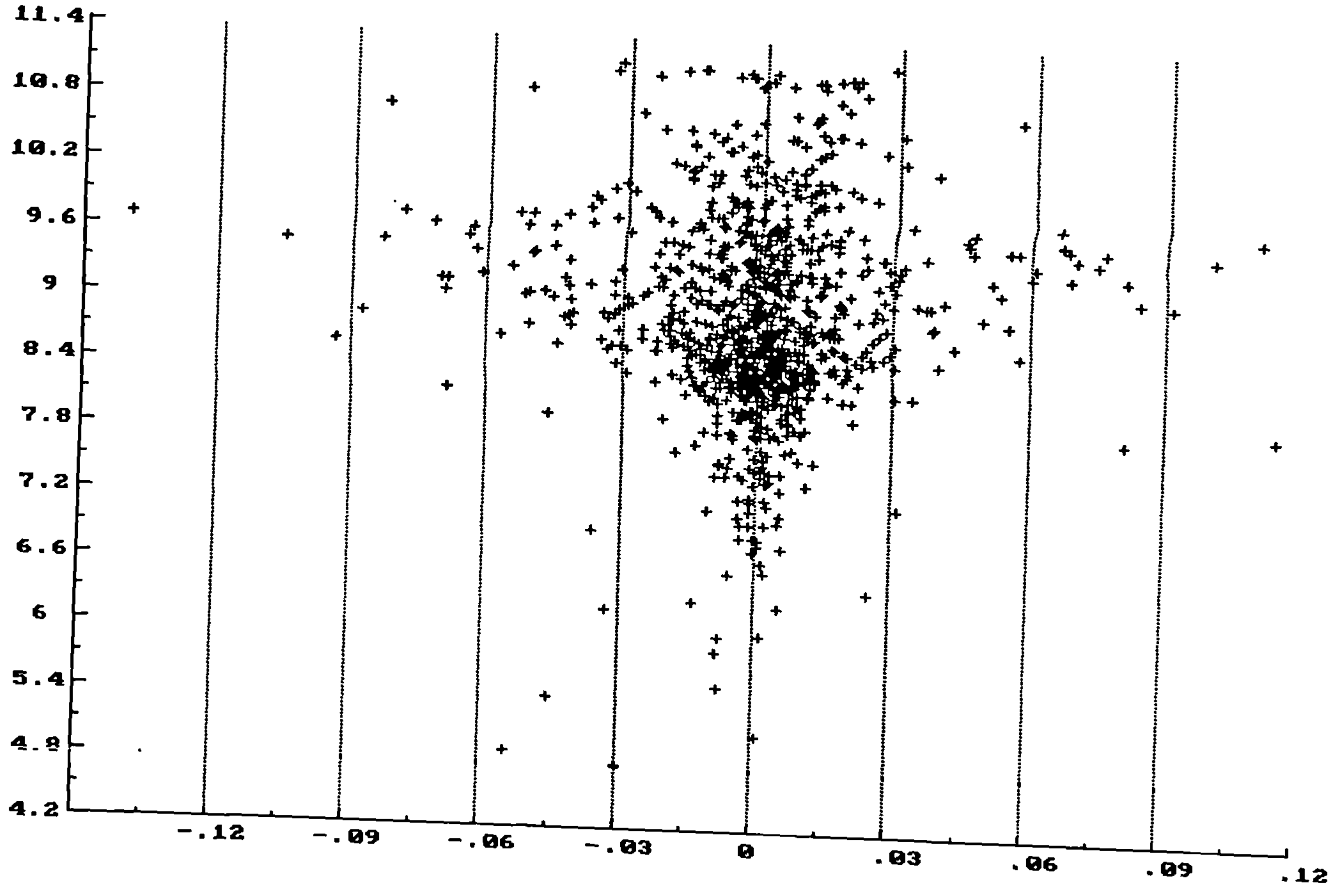


Figure 5.8

Plot of Detrended Log Volume against Price Returns (WTI 1984-88)



Alternatively a large dispersion of information (of a particular category of precision) among market agents gives a plot where increasing volume is associated with an increasing dispersion of the price change distribution, thus yielding a ∇-shape plot. If we assume that the precision of information in oil futures markets is fixed, then with reference to the proposition of the Blume *et al* (1994) model of volume, information and volatility, the nature of the relation between volume and price change (illustrated in Figures 5.6 to 5.8) are suggestive of futures markets which experiences a wide dispersion of information. Since the V-shape relationship predicted by the Blume *et al* model is not detectable in these plots we are unable to make inference on the precision of information in the oil futures markets. The plots generated by Blume *et al* to illustrate the effects of different information precision on the volume-volatility relation cannot be readily provided using real data since information precision is difficult to model in this way. This is the reason for us assuming a fixed precision of information.

A further important observation is that there appears to be no apparent difference between the volume associated with negative or positive price changes, as the plots of volume are evenly distributed about the volatility mean zero line in every case. This observation is consistent with Karpoff's assertion that the direction of price change and the level of trading volume should not be correlated in futures markets. It is also consistent with agents reacting in an unbiased fashion to both price rises and price falls, and as such offers evidence in favour of efficiency in futures markets.

We have seen thus far, preliminary evidence from Figures 5.6 to 5.8 suggesting that volume is symmetric to the sign of the price change. In the following we present statistical evidence in further support of this finding. For all three data series the negative and positive price changes are separated into groups together with their corresponding trading volumes. This generates two series of trading volume, one associated with price rises and the other with price falls. Summary statistics for each of the volume groups are presented in Table 5.2. It is evident from the results that oil futures markets do indeed exhibit symmetric trading volume responses to price changes of opposite signs. As such we support the Karpoff hypothesis that for futures markets the direction of price change does not dictate the 'direction' or size of trading volume.

Table 5.2

Summary Statistics for Trading Volume Respective of Sign of Price Change

Market	Observations	Trading Volume		Tests	
		Mean	Variance	t-tests	F-tests
Brent +ve	559	9.3155	.5382	1.34	1.00
Brent -ve	562	9.2530	.4352		
WTI(1) +ve	574	8.8816	.7012	1.16	.99
WTI(1) -ve	535	8.8822	.7981		
WTI(2) +ve	549	10.384	.2581	1.85	1.00
WTI(2) -ve	513	10.354	.2290		

Trading volume is the detrended logarithm of daily trading volume. The column labelled 'Market' is for the sub-samples of positive (+ve) and negative (-ve) price changes for each market group. The WTI(1) group represents the sample period from 1984 to 1988, while WTI(2) represents the 1990 to 1994 sample for the US futures market. The column labelled '*t*-test' tests for a statistically significant difference between the means of the positive and negative sub-samples i.e. H_0: $\mu_{+ve} = \mu_{-ve}$ with a critical value of 1.96 at 5%. The column labelled 'F-test' tests for a statistically significant difference between the variances for the sub-samples within each market group. Here the 5% critical value is 1.00 for the null hypothesis that the two variances are the same.

Volume and Absolute Price Change

Figures 5.9 to 5.11 provide a further dimension to our understanding of the volume-price-variability relation, giving a scatterplot of detrended log volume against absolute price changes for the three markets under inspection. Plots using a measure of volatility generated from a GARCH model (h_t), were also generated but were found to yield very similar results and are consequently relegated to an appendix to the chapter. The plots exhibit the positive price change-volume correlation predicted by the MDH. Furthermore, the patterns in these figures conform to the shape predicted by the theoretical model furnished by Blume *et al* (1994), and quite closely resemble the plots provided by the authors using a constructed and "well-behaved" set of data. From these figures oil futures markets are seen to exhibit the widely accepted contemporaneous positive correlation between volume and absolute price variability in futures markets.

To summarise, this section has found general support for the MDH in that the relation between price variability and trading volume is positive. In addition it is shown that volume is symmetric for price changes i.e. the direction of price change is not a relevant factor in explaining the relationship between price variability and volume. The study turns in the next section to more rigorous testing of this relation.

Figure 5.9

Plot of Detrended Log Volume against Absolute Returns (Brent 1990-94)

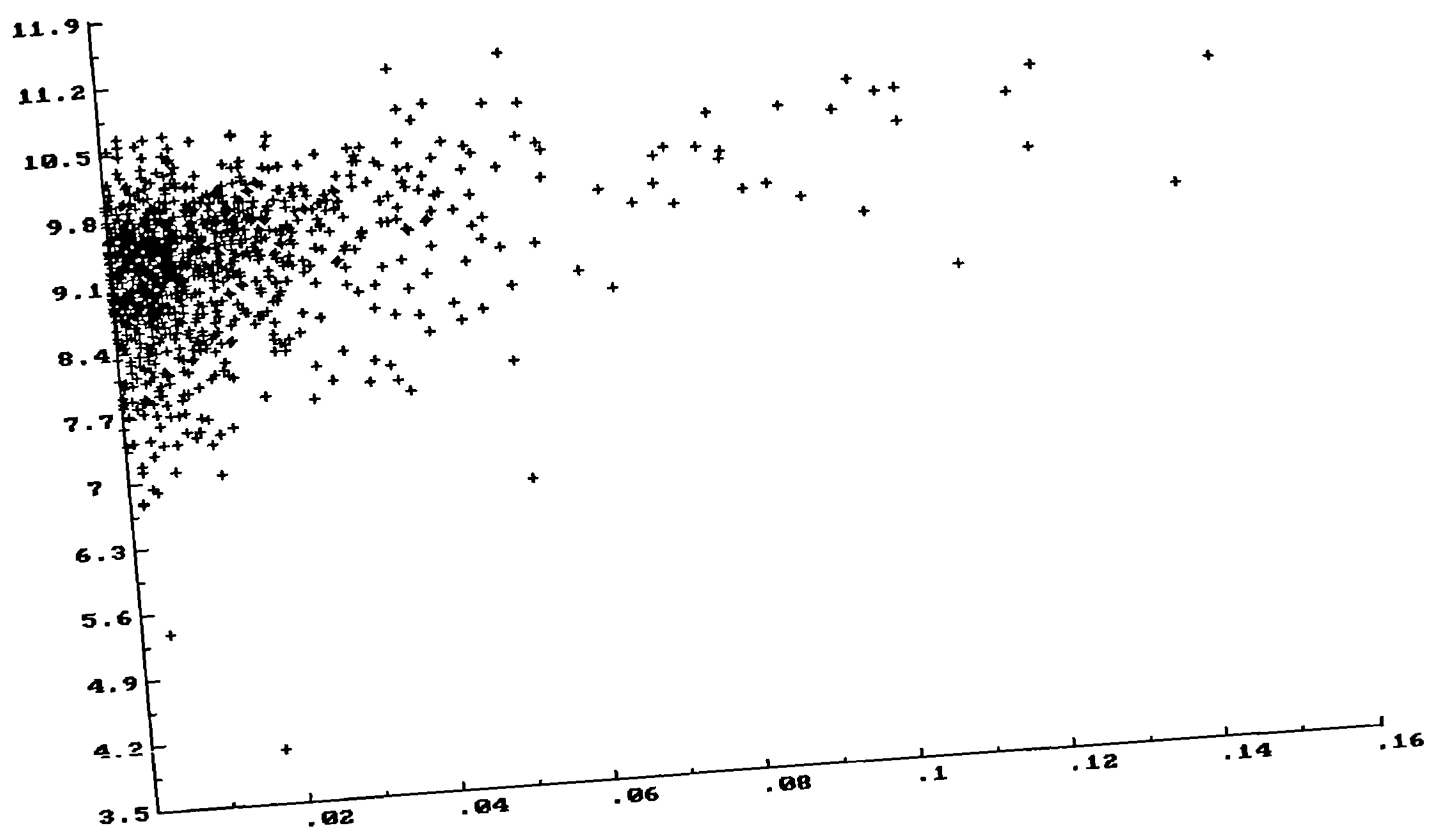


Figure 5.10

Plot of Detrended Log Volume against Absolute Returns (WTI 1990-94)

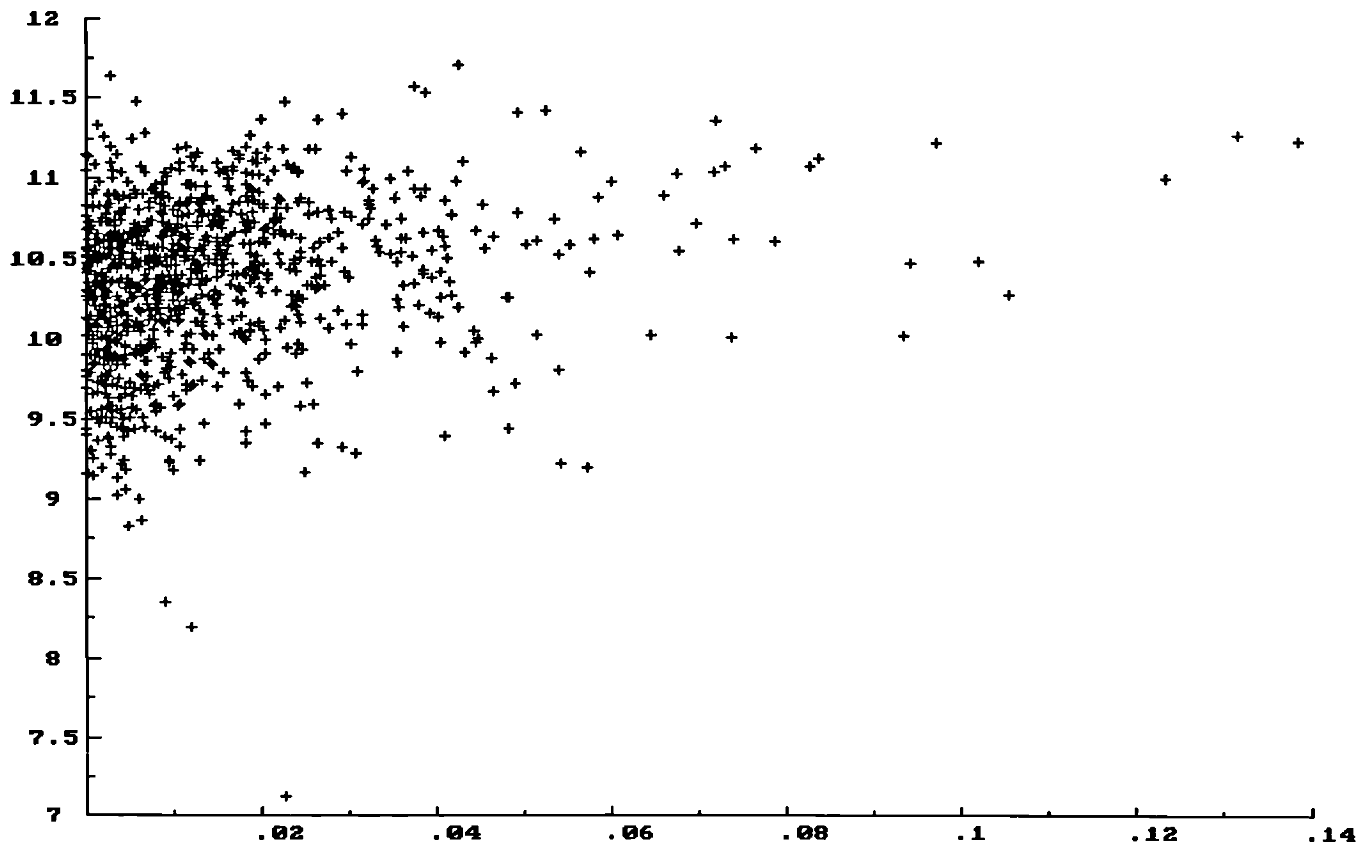
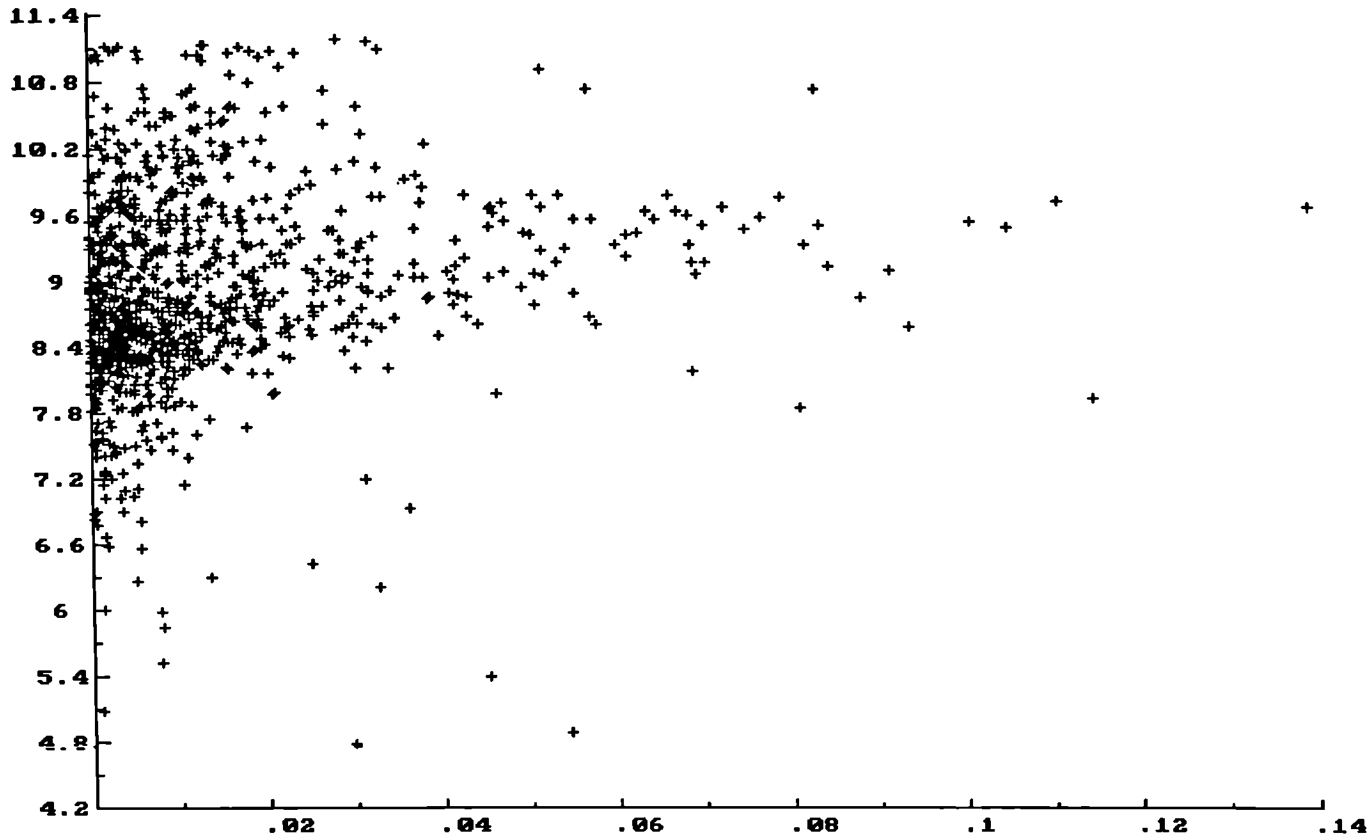


Figure 5.11

Plot of Detrended Log Volume against Absolute Returns (WTI 1984-88)



5.7 Empirical Results

GARCH Analysis Results

As stated earlier, the view held here is that the practice of introducing volume figures into a GARCH model may be considered to be more a test of whether volume provides an adequate proxy for the information variable than a test of the volume-volatility relation. In terms of this investigation, the effect of introducing a measure of trading volume into the GARCH equation for volatility is broadly similar for all markets studied here. All of the volume variables are significant in the GARCH models but are numerically very small and their impact on the GARCH coefficients is negligible; for each model $\gamma > 0$ but a_1 and b_1 remain significant. In no case does volume remove the GARCH effect, thus conflicting with the findings of Lamoureux and Lastrapes (1990) and suggesting that volatility is better explained by previous volatility rather than volume. This finding holds for both contemporaneous and lagged volume as well as the change in volume. These results lead to the interpretation that volume does not proxy for information as such.[72] The failure of volume to proxy for information could be attributed indirect support from the proposition by Blume *et al* (1994) that volume provides information about the dispersion and quality of information signals, rather than representing the information signal itself. This subtle difference in the role of volume would explain the statistical significance of volume without requiring it to explain volatility. From the results we propose that trading volume is an inappropriate surrogate for the rate of information arrival variable in the case of oil futures.

[72] An alternative explanation could be that volume does proxy information, but that information does not explain price volatility as measured by the GARCH process. This option is considered to be highly unlikely given the results of Chapter 2 and related literature.

Table 5.3

GARCH Models of Price Volatility

$$\Delta F_t = \alpha + \epsilon_t$$
$$h_t = a_0 + a_1 \epsilon'_{t-1} + b_1 h_{t-1}$$

GARCH Coefficient	Series		
	Brent	WTI(1)	WTI(2)
a_0	.543E-5 (4.850)	.228E-5 (4.407)	.0205E-5 (4.093)
a_1	.115 (10.134)	.116 (8.309)	.081 (8.526)
b_1	.877 (19.740)	.886 (17.448)	.914 (14.045)

Table 5.4a

GARCH Models of Price Volatility with Contemporaneous Volume

$$\Delta F_t = \alpha + \epsilon_t$$
$$h_t = a_0 + a_1 \epsilon'_{t-1} + b_1 h_{t-1} + \gamma V_t$$

GARCH Coefficient	Series		
	Brent	WTI(1)	WTI(2)
a_0	.303E-5 (.0054)	.235E-4 (.012)	.205E-5 (4.093)
a_1	.117 (10.047)	.121 (8.359)	.081 (8.472)
b_1	.874 (18.395)	.879 (17.607)	.914 (10.517)
γ	.624E-6 (5.058)	.296E-6 (4.661)	.207E-6 (4.219)

Table 5.4b

GARCH Models of Price Volatility with Lagged Volume

$$h_t = a_0 + a_1 \epsilon_{t-1}^2 + b_1 h_{t-1} + \gamma V_{t-1}$$

GARCH Coefficient	Series: Brent	WTI(1)	WTI(2)
a_0	.537E-5 (4.814)	.311E-4 (.108)	.366E-3 (.832)
a_1	.111 (10.127)	.117 (8.340)	.081 (8.498)
b_1	.879 (18.339)	.884 (19.909)	.914 (13.459)
γ	.261E-6 (4.347)	.273E-6 (4.529)	.202E-6 (4.137)

Table 5.4c

GARCH Models of Price Volatility with First Difference of Volume

$$h_t = a_0 + a_1 \epsilon_{t-1}^2 + b_1 h_{t-1} + \gamma (V_t - V_{t-1})$$

GARCH Coefficient	Series		
	Brent	WTI(1)	WTI(2)
a_0	.376E-5 (3.569)	4.282 (1.004)	.134E-4 (9.688)
a_1	.102 (9.631)	.082 (8.583)	.131 (10.685)
b_1	.892 (17.111)	.925 (19.576)	.774 (16.007)
γ	.274E-4 (8.937)	.145 (15.875)	.402E-5 (8.833)

Table 5.4d

GARCH Models of Price Volatility with Contemporaneous Squared Volume

$$h_t = a_0 + a_1 \epsilon_{t-1}^2 + b_1 h_{t-1} + \gamma V_t^2$$

GARCH Coefficient	Series		
	Brent	WTI(1)	WTI(2)
a_0	.559 (4.931)	.417 (.018)	.018 (.332)
a_1	.116 (9.988)	.124 (8.409)	.081 (8.449)
b_1	.873 (18.063)	.876 (16.444)	.913 (11.224)
γ	.689E-7 (5.202)	.363E-7 (4.893)	.207E-7 (4.353)

GMM Results

Models were constructed for the five samples considered with each model being identified according to the test provided by Hansen (1982), which is χ^2 (π-q) distributed where π is the number of instruments, and q is the number of variables in the structural equation system as given in equation (5.12). In this case q = 4. The instruments used were predetermined values of volume and volatility up to 5 lags.

The variables of primary interest in the system examined for this study are the coefficients on the contemporaneous value of volatility in the volume equation i.e. α_1 in equation (5.12), and volume in the volatility equation; γ_1 in equation (5.12). The results are presented in Table 5.5 and demonstrate that in all full-sample cases the contemporaneous variables are significant, thereby indicating a contemporaneous relation between volume and volatility, and implying that both variables are endogenous to the system. For the Gulf period however, the presence of contemporaneous volatility in the volume equation is found not to be statistically significant, a finding which is discussed below.

The common endogeneity of the volume and volatility variables suggests that they are both driven by an exogenous variable, assumed here to be the rate of information arrival. The above findings from the GMM model, in conjunction with the preliminary evidence cited in Section 5.5 can be seen as providing strong evidence in support of the MDH.

Table 5.5

GMM Results

$$V_t = \alpha_0 + \alpha_1 h_t + \beta_1 V_{t-1} + \epsilon_t$$
$$h_t = \gamma_0 + \gamma_1 V_t + \delta_1 h_{t-1} + u_t$$

	Brent 1990 - 1994		WTI 1984 - 1988	WTI 1990 - 1994	
	Full	Gulf	Full	Full	Gulf
α_0	4.820 (16.091)	4.047 (6.295)	3.334 (10.568)	5.110 (14.197)	4.063 (12.101)
α_1	1.253 (5.220)	-.190E-2 (-.308)	1.025 (2.246)	1.533 (22.901)	.194 (1.008)
β_1	.441 (14.955)	.584 (8.811)	.633 (18.263)	.478 (13.893)	.602 (18.043)
γ_0	-.875 (-6.051)	-8.145 (-4.141)	.149 (2.103)	-2.821 (-13.035)	-.968 (-5.417)
γ_1	.119 (7.748)	.871 (4.234)	.064 (4.497)	.526 (22.272)	.111 (6.162)
δ_1	.1889 (1.754)	.852 (6.782)	.971 (8.246)	.365 (3.028)	.383 (3.497)

The Gulf period is taken from 1/8/90 to 28/2/94 and represents 147 and 146 observations for the Brent and WTI markets respectively. The row labelled 'Hansen' is for the Hansen (1982) test which can be used as a test of identification. The test is χ^2 (π-q) distributed where π is the number of instruments, and q is the number of variables in the structural equation system. All models pass the test of identification at the 5% level. Figures in parentheses are *t*-statistics.

The Market Size Effect

We examine two types of market size effects for volume-volatility relations; the absolute effect is considered by comparing the IPE Brent market with its relatively larger NYMEX WTI relation, while the WTI market is compared at different stages in its development to investigate market maturity effects. Results presented in Table 5.1 indicate the consistent phenomena that the larger a market is, the less variable its trading volume becomes. This observation is explained by the probability that as markets mature or become very large they are less susceptible to periods of illiquidity which could be a major causal effect of variability in volume. In illiquid markets volume will, by definition, be low but as prices are forced to extremities as a response volume will again increase. These findings broadly support the proposition by Tauschen and Pitts (1983) that greater trading volume stabilises prices.

Examination of the correlation between volume and measures of price variability, do not suggest any clear growth in volatility as markets become larger. In addition, casual observation comparing the figures for the volume-volatility relation (Figures 5.3 to 5.11) also fail to suggest a significant maturity/size effect on price variability. These results further support the notion that the inherent volatility of markets does not increase as trading volume rises.

The Rate of Information Flow Effect

In order to test for changes in the volume-price-variability between what may be termed 'normal' periods and those periods characterised by significant news events we investigate the Gulf Conflict. Initial analysis concentrates upon a comparison between the general market statistics presented in Table 5.2, with comparable statistics for the Gulf Conflict period as provided in Table 5.6 below. As in the full-sample case the markets do not demonstrate a difference between trading volume associated with price rises and price falls, and so we may infer that the volume-price-variability relation remains symmetric in times of increased information arrival. The most notable difference, however, is that the variance of trading volume is substantially lower during the Gulf period. While this may be an artifact of the data in that the relatively smaller sample of the Gulf period has less scope for large shifts in volume, we may explain this by the fact that the fact that during that period interest in oil futures was consistently high. Again we note that the mean volume for the Gulf period was not substantially different to that for the whole sample which again could be explained by the relative sample sizes.

The second level of investigation for the Gulf effect is carried out by running the GMM model specifically for that period. Results from this analysis are presented in Table 5.5 along side the full-sample results. The most notable effect here is that the contemporaneous volatility in the volume equation is statistically insignificant for both the US and UK markets, see α_1 in Table 5.5. This contrasts with the full-sample case where the variable is significant for both markets. This result is interpreted as suggesting that during the Gulf Conflict trading volume was not being driven by information to the same extent than in less eventful periods. One possible explanation for this effect is that the concern and uncertainty caused by the events of the Gulf Conflict led both hedgers and speculators to rush onto the market in a spate of panic trading. Since 'external' influences such as apprehension over the future supply of oil and general uncertainty were now driving trading volume, the effects of volatility itself could have been somewhat overshadowed, thus explaining its diminished influence in the GMM model.

Table 5.6

Summary Statistics for Trading Volume Respective of Sign of Price Change during the Gulf Conflict

Market	Observations	Trading Volume		Tests	
		Mean	Variance	t-tests	F-tests
Brent +ve	65	9.080	.238	1.67	.96
Brent -ve	82	9.099	.260		
WTI +ve	79	10.446	.300	1.93	.98
WTI -ve	68	10.324	.258		

Trading volume is the detrended logarithm of daily trading volume. The column labelled 'Market' is for the sub-samples of positive (+ve) and negative (-ve) price changes for each market. The period covered is from 1/8/90 to 28/2/91 which yields a total of 147 observations. The column labelled '*t*-test' tests for a statistically significant difference between the means of the positive and negative sub-samples where the 5% critical value is 2.00. The column labelled 'F-test' tests for a statistically significant difference between the variances for the sub-samples within each market. Here the 5% critical value is 1.53 for the null hypothesis that the two variances are the same.

5.8 Summary and Conclusions

The primary findings of this investigation into volume-volatility relations for oil futures is that volume is not an adequate proxy for the rate of information flow but that volume and volatility are contemporaneously related and are both driven by information. These results provide strong empirical support for the MDH of Clark (1973) and Harris (1987) and equally reject Copeland's notion of a sequential model for volume and volatility.

The study has also investigated a number of issues identified by Karpoff (1987) as worthy of further research: whether the price-variability-volume relation is asymmetric; whether the size of a market influences the relationship; and if the rate of information arriving on the market affects the relation. In this chapter these issues have been addressed. In the first case results suggest that the magnitude of trading volume and the dispersion of price changes are symmetric and as such we do not expect the level of trading volume to be affected by the direction of price changes. Moreover, volume and volatility exhibit the positive correlation expected by theoretical models.

As far as the market size and information effects are concerned the study finds no evidence that volume-volatility relations are sensitive to market size, but it does note that the variability of volume is smaller in larger markets which is probably due to sufficient liquidity there. By contrast, changes in the nature of the rate of information flow do have a pronounced effect on volume-volatility relations, with the effect being interpreted in this case as due to greater uncertainty.

APPENDIX

Figure A5.1

Plot of Detrended Log Volume against Price Volatility (Brent 1990-94)

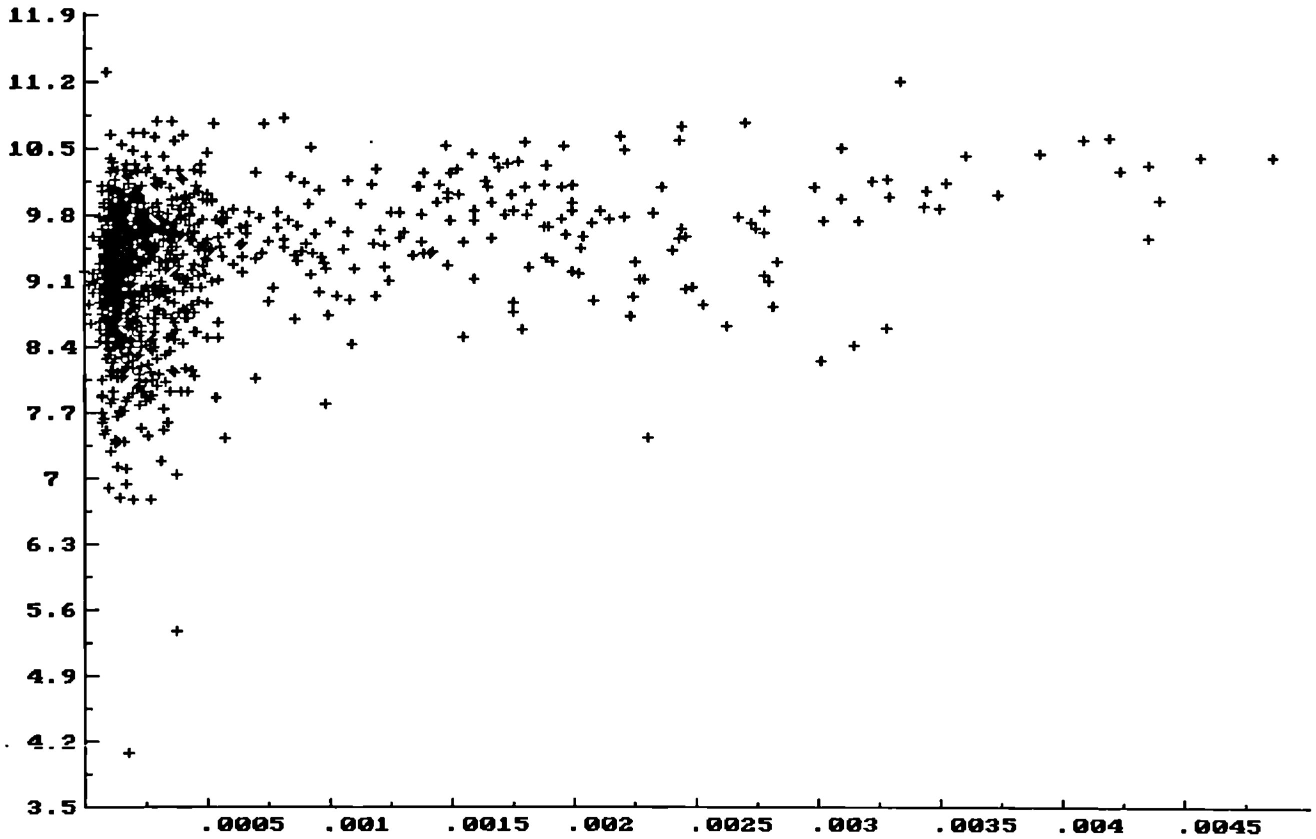


Figure A5.2

Plot of Detrended Log Volume against Price Volatility (WTI 1990-94)

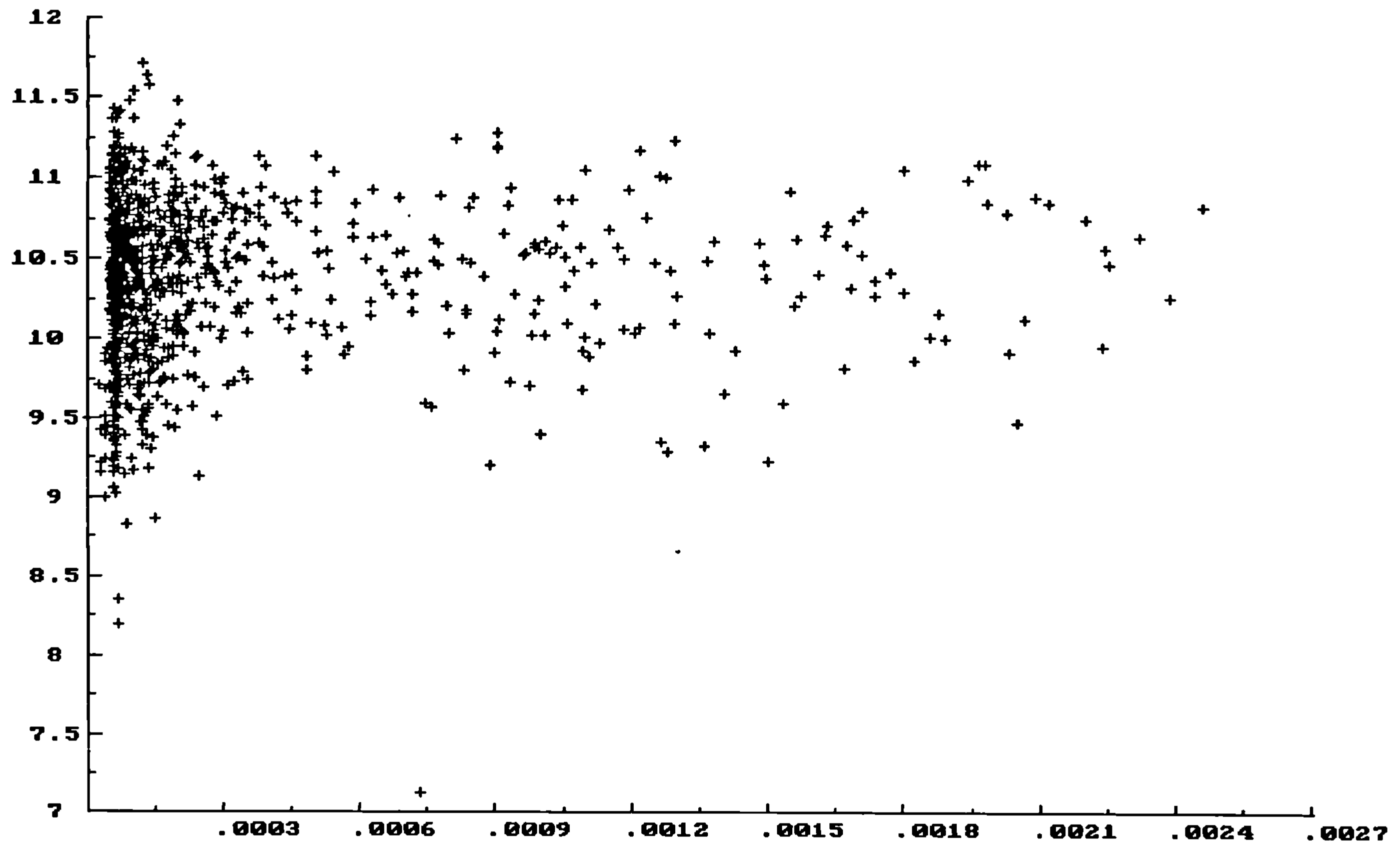
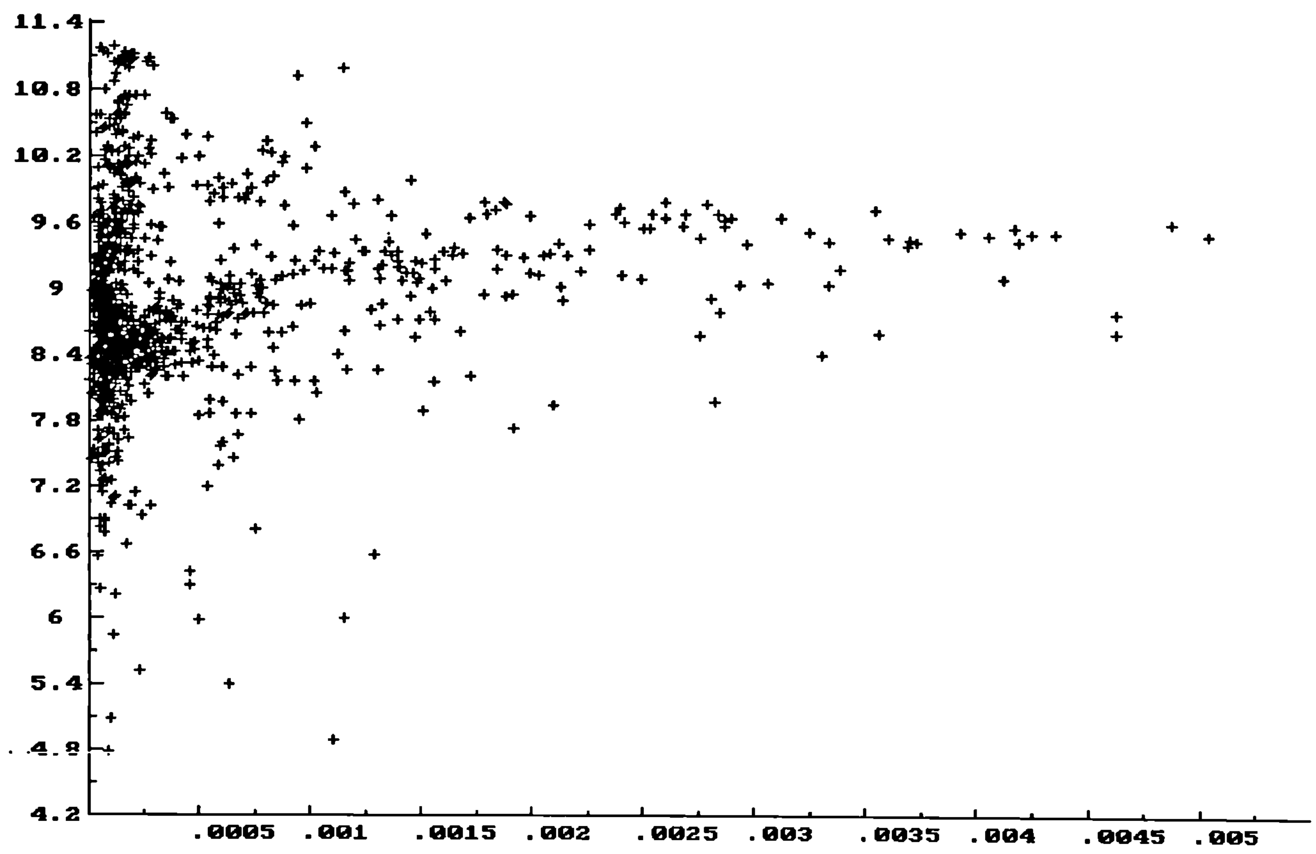


Figure A5.3

Plot of Detrended Log Volume against Price Volatility (WTI 1984-88)



CHAPTER 6

CONCLUSION

6.1 SUMMARY OF FINDINGS

> "It should be remembered that oil is not an ordinary commodity like tea or coffee. Oil is a strategic commodity. Oil is too important a commodity to be left to the vagaries of the spot or the futures markets, or any other type of speculative endeavour." Ahmed Zaki Yammani, Saudi Oil Official.[73]

The above statement is not strictly correct. We can accept the view that oil is not an ordinary commodity, indeed it is the most important commodity in the world, and its economic significance assures it of a political importance unrivalled by any other commodity. It is also true that the industrialised nations of the world would suffer much less from a shortage of tea or coffee than from a shortage of oil. Ultimately though, despite its prominence oil *is* just another traded commodity, and is rightly left to the vagaries of spot and futures markets. This thesis has sought to investigate the effects of the 'vagaries' of futures markets on the spot price for oil, and to analyse the performance of those futures markets in their prescribed functions.

Futures exist in order to reduce the risks encountered by participants in volatile spot markets. In this regard the oil market is no different to many other markets and has

[73] Quoted in Yergin (1991).

been characterised by periods of particularly volatile prices. As was described in Chapter 1, the shift away from the more traditional term contracts for trading oil led to the emergence of the spot market as the main arena for oil trading. This in turn led to the growing need for a mechanism for transferring price risk, and crude oil futures markets were established as a response. This thesis has examined the role and functioning of such futures contracts for crude oil, with investigation centred around the world's two leading crude oil futures markets; the NYMEX and IPE futures markets.

The thesis presents four related empirical essays dealing with first, the impact of futures trading on spot price volatility, second the efficiency of futures markets with respect to their provision of unbiased estimates of future spot prices, third the price dominance of futures markets vis à vis spot prices, and finally the relationship within futures markets between volume, volatility and information. The general finding is that futures markets contribute to the informational content of spot markets, and are informationally efficient in themselves.

Since the rationale for establishing futures trading is that it reduces or transfers the price risk of its associated spot market, an obvious starting point for an analysis of the functioning of futures relates to their volatility effect on the underlying spot market. Chapter 2 investigates this issue and finds that the accusation that futures markets increase spot market volatility is a complex issue which has often been addressed with too simple a question. To properly examine the volatility question one should ask questions about the nature of changes to volatility and the reasons for those changes.

As shown in Chapter 2, "news volatility" may increase due to markets becoming more informationally efficient, with volatility persistence declining for the same reasons. The argument proposed here is that the volatility effects of futures trading on a spot market can largely be attributed to improvements in the discovery and impounding of information brought by futures. The widely investigated volatility effects of futures on spot prices can thus be explained in terms of information effects, and these information effects are described with the price discovery functions of futures markets. In this framework it becomes clear that the intense concern over the volatility effects of futures rests implicitly upon the assumption that futures discover information first and that this discovery finds its way to the spot market price. Chapter 2 further contributes to the current literature by proposing a method for extracting the noise element of price fluctuations in order to refine and clarify investigations of volatility transference. The use of state space modelling in this regard gives an indication as to whether increases in spot price volatility due to futures trading are the result of enhanced information discovery or noise trading caused by speculators entering the market.

When futures markets are found to be an effective arena for the discovery, interpretation and dissemination of information then they should be able to provide optimal predictions of the future spot price. It is this question which constitutes the empirical investigation in Chapter 3, where the efficiency of futures as defined by their ability to provide an inter-temporal price discovery function is researched. This investigation is motivated by the need to understand whether the current futures price fulfils its prescribed role of providing an unbiased prediction of the future spot price.

It is this assumed quality which leads to the view that futures offer a vehicle for reducing the risk due to price fluctuations, and if traders are to make decisions based on futures' prices then the effectiveness of futures in this role is crucial. The investigation undertaken in Chapter 3 adds to the current literature by considering short-term efficiency in addition to the commonly researched long-term efficiency of futures contracts. Results from cointegrating regressions and an analysis of ECMs suggest that while futures markets can be efficient in the long-term, this conclusion does not necessarily hold over the short-term. These conclusions also warn of the problems of testing only for long-term efficiency when investigating the efficiency of futures markets.

The findings of Chapter 2 suggest that impact of futures on spot prices was attributable to improvements in the discovery and impounding of information. This is not to say, however, that prices in futures markets *cause* spot prices, although there is a clear interaction between the markets' prices. We propose that any appearance of causality is largely attributable to the fact that spot and futures prices will respond in the same way to information events, and that futures markets are better able to register those information events which will later find their way to the spot market. This relationship is the subject of investigation for Chapter 4 which focuses on the relative speed of reaction to information by spot and futures markets. This function, termed dominance, gives direct insights into the relative abilities of spot and futures markets to respond to the arrival of new information. The findings of Chapter 4 imply that futures markets are generally better able to respond to information than their spot markets. The observed tendency for futures prices to impound information faster than a like response in the spot market corroborates the findings of Chapter 2 which rest on the assumption that the volatility effects of futures trading observed on the spot market were a direct consequence of improved information discovery. The main finding of Chapter 4, however, is that previous studies of the dominance relationship have failed to account for all routes through which information passes between spot and futures markets, and have not properly addressed the question of dominance patters changing over time. Chapter 4 addresses both of these questions, first with the development of a new, generalised model for measuring dominance, and second by use of time-varying estimation techniques. Findings suggest that current models of dominance do indeed fail to account for all information routes between markets, and that dominance patters exhibit substantial time variance.

While the first three empirical chapters deal with the relationship between futures markets and spot markets in the context of information, Chapter 5 looks at the futures market in itself and probes the issue of the relationship between futures price volatility, trading volume and the role of information in that relationship. The research is presented on three levels, the first of which examines the general volume-price-variability relation and finds that both variables are positively related. Moreover, volume is found to respond symmetrically to both price rises and price falls. The second phase of the examination investigates the notion that the level of trading volume can explain volatility by acting as a surrogate for information arrival. Based on the assumption that information drives prices, the results suggest that volume is not an adequate proxy for the rate of flow of information, a finding which attests to the efficiency of futures prices by excluding the possibility of forecasting price changes using the volume variable. Finally the study undertakes an analysis of contemporaneous movements in prices and volatility and concludes that both variables are driven by the same variable which is assumed to be information.

6.2 POLICY IMPLICATIONS

A general theme running through this thesis has been that greater regulatory controls on futures markets in the form of higher margins, limits on price movements and other trading restrictions are potentially damaging to both spot and futures markets. Where observed increases in short-run volatility in the post-futures era is due to improved market efficiency, then the imposition of tighter regulatory control could serve to reintroduce market frictions removed by futures trading. To highlight the potential damage of regulation we may refer to the problems encountered by the Chicago onion futures contract which was eventually banned on the grounds that they induced extra volatility in the spot market. Working (1960) argues that the observed increase in spot market volatility was due to hedging pressures caused by insufficient speculation in the futures market. By imposing restrictions on a futures market, regulators may unwittingly promote spot price volatility by dissuading speculators from entering the market thus reducing its liquidity. Correct identification of the nature and causes of volatility are thus necessitated before regulatory controls are imposed.

Of interest to the policy maker too could be the results from Chapter 3 of this thesis which suggest that the notion of futures market efficiency has to be addressed in greater detail than that previously given. This study has highlighted not only that tests of long-term efficiency require a number of elements to be examined, but also that short-term efficiency is an aspect worthy of investigation. Where futures markets are to be judged by their ability to provide unbiased forecasts of future spot prices, the judgement procedure must take account of both long-term and short-term efficiency.

Chapter 4 highlighted the tendency for the dominance pattern of an asset market to vary through time and experience periods of either spot or futures dominance. The implication of this research for the policy maker is that the dominance pattern of the market must be assessed and understood prior to the imposition of new regulations, otherwise the outcome of those regulations may be barren, or more seriously, counter to the original intention. Thus, policies aimed at reducing spot price volatility by curbing futures activity may not have the desired effect if price is discovered predominantly in the spot market. Where prices are discovered in futures, then curbing futures' activity will quite possibly lead to interference in, or removal of the links between the spot and futures markets. This could have the adverse effect of 'insulating' spot prices from the information contained in futures and may thus lead to a lower information content in spot prices.

A final question for those calling for tighter restrictions to be placed on futures markets is that if futures markets are rendered ineffective, then will not some other type of institution and instrument evolve to satisfy the demand which futures currently supply? If the mechanism for removing risk from producers and users of commodities were to disappear, how would this manifest itself in the price of that commodity, and how would this affect the final consumer and the economy as a whole?

6.3 Direction of Future Research

The investigation in Chapter 2 suggested that for the same market different results for the presence of noise are suggested dependent upon the data frequencies used; namely that noise trading appears to increase on a daily basis, but declines when measured on a weekly basis. The implications of this for studies of noise or pricing efficiency are that results may be an artifact of the observation interval utilised. Certainly it would be interesting to test this phenomena for other markets on an empirical basis, and also to generate discussion as to the market mechanisms which could explain such an observation. The direction of such research would potentially be based on the notion that markets will achieve efficiency at some threshold of time interval, beyond which market mechanisms or agent behaviour prevent the disassociation of noise and information.

In addition, it would be interesting to further test the use of the Kalman filter for identifying the noise component of price volatility, since the interpretation of this practice is somewhat ad hoc. It would be constructive to identify a way of better comparing the change in the contribution of noise to volatility over the two periods considered.

In Chapter 4 the GDM was developed under the assumption that the convenience yield for a nearby futures contract was trivial. It would be constructive to relax this assumption and investigate the impact of a non-trivial convenience yield on the dominance relationship. This may be achieved by calculating the implied convenience yield between two adjacent maturities, and using this as a basis for estimating the convenience yield in the latter contract. Such research has already received attention (see Brennan Gibson and Schwartz (1990), and Brennan (1991)), but has not as yet been applied to studies of dominance. The results of such research could be used to further refine the model of dominance presented in this thesis.

Chapter 5 investigated volume and volatility relations with reference to information as the variable explaining their commonalities. Some studies (see for example Grammatikos and Saunders (1986)) have considered the role of maturity in explaining this relation, with maturity proxying the directing variable. This was not considered within the current research but could make a useful contribution to our understanding of the relation for oil markets. Moreover, it would be interesting to test whether volatility increase nearer to maturity as suggested by Samuleson (1965) against the suggestion forwarded by Anderson and Danthine (1983) that this is not inevitable and depends, rather, on the time at which the main resolution of uncertainty occurs. If a sufficiently large amount of uncertainty is resolved prior to the maturity month, then it is feasible that volatility will decline as maturity approaches. An investigation of a maturity effect in volume-volatility relations would thus be of interest.

GLOSSARY

API	American Petroleum Institute scale for measuring the specific gravity of crude oil
Barrel	Basic unit of measurement for crude oil; equivalent to 42 US gallons
Brent	Blend of crude oil from the North Sea
CBOT	Chicago Board of Trade
Cracking	Sophisticated technique for refining crude oil
Distillation	Most basic form of refining crude oil
EFP	Exchange for Physicals: cash settlement futures which permit users to make or take delivery of physical oil
Heavy crude	Crude oil with an API gravity below 24°
IPE	International Petroleum Exchange (London)
Light crude	Crude oil with an API gravity in excess of 35°. (Brent Blend typically has an API of 38°, while WTI crude has an API of 40°)
Marker crude	Benchmark crude oil
NYMEX	New York Mercantile Exchange
OPEC	Organisation of Oil Producing Countries
Paper barrel	Quantity of oil represented by a futures contract
SIMEX	Singapore International Monetary Exchange
Sour crude	Crude oil containing more than 0.5% sulphur
Sweet crude	Crude oil containing less than 0.5% sulphur
Wet barrel	Physical oil (see paper barrel)
WTI	West Texas Intermediate crude oil

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