

INFORMATION TO USERS

The most advanced technology has been used to photograph and reproduce this manuscript from the microfilm master. UMI films the text directly from the original or copy submitted. Thus, some thesis and dissertation copies are in typewriter face, while others may be from any type of computer printer.

The quality of this reproduction is dependent upon the quality of the copy submitted. Broken or indistinct print, colored or poor quality illustrations and photographs, print bleedthrough, substandard margins, and improper alignment can adversely affect reproduction.

In the unlikely event that the author did not send UMI a complete manuscript and there are missing pages, these will be noted. Also, if unauthorized copyright material had to be removed, a note will indicate the deletion.

Oversize materials (e.g., maps, drawings, charts) are reproduced by sectioning the original, beginning at the upper left-hand corner and continuing from left to right in equal sections with small overlaps. Each original is also photographed in one exposure and is included in reduced form at the back of the book.

Photographs included in the original manuscript have been reproduced xerographically in this copy. Higher quality 6" x 9" black and white photographic prints are available for any photographs or illustrations appearing in this copy for an additional charge. Contact UMI directly to order.



University Microfilms International
A Bell & Howell Information Company
300 North Zeeb Road, Ann Arbor, MI 48106-1346 USA
313/761-4700 800/521-0600

Order Number 9108123

**Weak form efficiency tests and the NYMEX 321 crack spread:
Applications of cointegration theory**

Jones, Nevin Ronald, Ph.D.

City University of New York, 1990

U·M·I

**300 N. Zeeb Rd.
Ann Arbor, MI 48106**

A

**Weak Form Efficiency Tests and the NYMEX 321 Crack
Spread: Applications of Cointegration Theory**

by

Nevin R. Jones

A Dissertation submitted to the Graduate Faculty in
Economics in partial fulfilment of the requirements
for the degree of Doctor of Philosophy, the City
University of New York.

1990

This manuscript has been read and accepted for the Graduate Faculty in Economics in satisfaction of the dissertation requirement for the degree of Doctor of Philosophy.

August 6, 1990
Date

Ronald Anderson
Chair of Examining Committee

August 6, 1990
Date

Michael Grossman
Executive Officer

Professor Ronald Anderson

Professor Salih Neftci

Supervisory Committee

The City University of New York

Abstract

Weak Form Efficiency Tests and the NYMEX 321 Crack

Spread: Applications of Cointegration Theory

by

Nevin R. Jones

Advisor: Professor Ronald Anderson

The past several years have witnessed a veritable avalanche of theoretical papers dealing with the question of the weak form efficiency properties of a variety of asset markets including those for housing, Treasury Bills, stocks, and more recently oil futures.

This study is part of the same broad genre and specifically fixes upon the energy futures market as represented by the New York Mercantile Exchange (NYMEX) and its 321 crack spread. The essential objective of our focus is to provide evidence concerning the theoretical adequacy of the Samuelsonian Martingale Model as a reasonable characterization

of the behavior of futures prices in the NYMEX energy complex.

In the above regard, following the introduction of some background material on the NYMEX energy contracts we introduce a theoretical model of the generalized crack spread and thus establish the relevant theoretical underpinnings of the 321 crack spread. Next we apply standard regression techniques to the price series in the individual markets to ascertain their stochastic properties. Applying Dickey-Fuller econometric techniques to the results of these standard regressions reveal that the individual markets are weak form efficient. As a refinement, given the presence of contemporaneous correlation in the cross sectional error terms, we model the individual price series using covariance and error components analysis and again cannot reject the finding that these markets are weak form efficient.

Finally, we introduce a framework of analysis based upon the theory of cointegrated processes and Error Correction Modeling (ECM) and are able to establish in fifty percent (50 %) of the cases studied, clear evidence of weak form inefficiency and by implication, opportunities for surplus profits to be successfully speculated away.

Preface

This study grew out of the observation that there was an apparent preference of traders on NYMEX to trade the 321 crack spread over the wide range of spreads available to them. The question became, was this merely an old comfortable rule of thumb or was there an underlying micro-economic optimizing foundation behind this strategy?. Also, does this spread strategy lead to market outcomes that are Fama efficient?

Our investigations in part revealed that although there are indeed some micro-economic underpinnings for the 321 crack spread, a rigorous econometric analysis indicates a strong tendency towards generating some inefficient market outcomes.

In carrying out this study I have received help and counsel from a number of very special individuals. To Professor Ron Anderson I am extremely indebted for his time, his many helpful suggestions and ideas and most of all for his patience. I am thankful to Professors Salih Neftci and Michael Grossman for teaching me all the econometrics and micro theory I know (its not your fault Guys!!!) and for their encouragement in many intangible ways. I thank Ms. Ann Holzman secretary of the CUNY Graduate Economics Department for all of the wonderful help she has given me these several years. I also owe a great debt to Dr. Andii Bannerjee of BellCore, for

the hours of mindnumbing discussions that we had about this topic and for his many ideas and suggestions. I should add that the usual disclaimers apply here and hence none of the above individuals are in any way responsible for the remaining errors or deficiencies.

Finally, it is very rare that a task of this sort and of this importance is undertaken and finished without the enormous help, patience, encouragement and sacrifice of one's family. In this regard, I am eternally indebted to my brother--Damani--, who, although severely ill with MS has been a constant source of wisdom, courage and encouragement... I love you Guy!!!!. To my Mom, who passed away before this project came to completion, I owe my life, character, passion for knowledge and love of family. I am also grateful to my other siblings Norman et. al., for believing in me and for their encouragements. To my wife Jennifer and my sons Hakiim and Omar I owe the greatest debt for their personal sacrifices, their love and understanding and for picking me up and carrying me when I tired along the way.

Table of Contents

	Page
Abstract	iii
Preface	v
List of Tables	ix
List of Illustrations	x
Chapter:1	
1.1 Introduction.....	1
1.2 The Refined Oil Complex and its underlying Futures Contracts.....	7
1.3 Benefits of Energy Futures Markets.....	12
Chapter 2:	
2.1 The Industry 321 Crack Spread.....	15
Chapter 3:	
3.1 Towards a Theory of the Generalized Crack Spread.....	19
3.2 Summary and Conclusions.....	29
Chapter 4:	
4.1 Data Description and Summary Statistics.....	31
Chapter 5:	
5.1 Market Efficiency and Weak Form Tests of Energy Product markets.....	49
5.2 Weak Form Tests of Efficiency in the NYMEX Energy Complex: Applications of Dickey-Fuller Analysis...	52

Chapter 6:

6.1 Weak Form Efficiency and the NYMEX 321 Crack:	
Tests and Analysis.....	66
6.2 Covariance Modelling of the Crack.....	67
6.3 Empirical Results.....	81
6.4 Summary and Conclusions.....	90
6.5 SUR Estimation of the 321 Crack.....	91
6.6 SUR Results.....	94

Chapter 7:

7.1 Cointegration Theory: Implications for	
Weak Form Tests.....	97
7.2 Summary and Conclusions.....	110

Chapter 8:

8.1 Grand Summary and Conclusions.....	112
Bibliography:	115

List of Tables

	Page
Table I.....	37
Table IIA.....	42
Table IIB.	43
Table IIC.	44
Table III.	45
Table IV	54
Table V.	55
Table VI.....	56
Table VII.....	61
Table VIII.	62
Table IX... ..	63
Table X... ..	64
Table XI.....	70
Table XII.	82
Table XIII.	88
Table XIV	89
Table XV	93
Table XVI	96
Table XVII.	102
Table XVIII.	107
Table XIX	108
Table XX	109

List of Illustrations

	Page
Figure 1.....	35

Chapter 1.

1.1 Introduction

Over the past two decades the theoretical financial literature has witnessed a rather heated debate on the idea of market efficiency and the possibility of constructing trading strategies that are capable of systematically outperforming simple buy and hold rules. Examples of this literature include: Osborne (1966)¹, Samuelson (1965)², Cootner (1967)³, Fama (1970)⁴, Mandelbrot (1966)⁵, Roll (1970)⁶ and Leroy

¹Osborne, M. (1966): "Brownian Motion in the Stock Market" Operation Research, Vol. 7, No. 2.

²Samuelson, Paul (1965): "Proof that Properly Anticipated Prices Fluctuate Randomly" Industrial Management Review, Vol. No. 2, pp 41-49.

³Cootner, P. (1967): The Random Character of Stock Market Prices, Cambridge, MIT Press: pp. 100-128.

⁴Fama, Eugene F. (1970): "Efficient Capital Markets: A Review of Theory and Empirical Work," Journal of Finance, Vol. 25, No. 2, pp 383-417.

⁵Mandelbrot, B. (1966): "Forecasts of Future Prices, Unbiased Markets, and 'Martingale' Models," Journal of Business, Vol. 39 No. 1, pp. 242-255.

(1973)⁷.

At a less general level, there have been tests of market efficiency applied to specific markets. In the area of T-Bills examples that come to mind include Rendleman & Carabini (1979)⁸, Puglisi (1978)⁹ and Cicchetti, Dale and Vignola (1979)¹⁰. Cargill and Rauser (1972)¹¹, and Praetz (1975)¹²

⁶(...continued)

⁶Roll, R. (1970): *The Behavior of Interest Rates*, New York: Basic Books.

⁷Leroy, S. (1973): "Risk Aversion and the Martingale Property of Stock Prices," *International Economic Review*, Vol. 14, No. 2, pp 436-446.

⁸Rendleman, R. and Carabini, C. (1979): "The Efficiency of the Treasury Bill Futures Market," *Journal of Finance*, Vol. 34 No. 4, pp 895-914.

⁹Puglisi, D. J (1978): "Is the Futures Market for Treasury Bills Efficient?" *The Journal of Portfolio Management*, Winter, pp. 64-67.

¹⁰Cicchetti, P, Dale, C and Vignola, A (1979): "Usefulness of Treasury Bill Futures as Hedging Instruments," *Journal of Futures Markets* Vol. 1, No. 3, pp 379-387.

¹¹Cargill, F. & Rauser, G. (1972): "Time and Frequency Domain Representations of Futures Prices as a Stochastic Process" *Journal of The American Statistical Association*, Vol. 67, No. 337, pp23-30.

¹²Praetz, P. (1975): "Testing the Efficient Market Theory on the Sydney Wool Futures Exchange" *Australian Economic Papers*, Vol. 14.

provide examples in the context of agriculture and livestock farming while Case & Shiller (1989)¹³ do so with respect to the market for single family housing.

With the passage of time, the theoretical focus has tended to shift increasingly toward the area of the energy markets. Thus Gjolberg (1985)¹⁴ studied the Rotterdam spot market for oil products to see if it satisfied the criteria for "weak form efficiency"¹⁵. He applied fairly simple statistical tests (e.g., the nonparametric runs test) to spot price data for gas oil (i.e., No.2 heating oil) and concluded that the market was not weak form efficient since spot price changes over daily, weekly and monthly time intervals were serially correlated.¹⁶

¹³Case K. E. & Shiller R. J. (1989): "The Efficiency of the Market for Single-Family Homes", American Economic Review, Vol. 79, No. 1 pp. 125-137.

¹⁴Gjolberg, O. (1985): "Is the Spot Market for Oil Products Efficient?," Energy Economics, October, pp 231-236.

¹⁵Markets are regarded as being weak form efficient when the equilibrium price quantity relationships are based upon an information set which includes all current and past prices of the commodity in question. In this and other regards, see: Fama, Eugene, F. "Efficient Capital Markets: A Review of Theory and Empirical Work" Journal of Finance, Vol. 25, (May) pp 383-417.

¹⁶Gjolberg's paper investigates the hypothesis that the spot oil market follows a random walk. There are no theoretically compelling reasons why spot markets should be efficient since, in the first place, they are often spatially dispersed and hence tend to operate
(continued...)

Focusing on the same market, Bird (1987) took a slightly more sophisticated statistical approach in evaluating the stochastic properties of its spot prices. Like Gjolberg, he found positive serial dependence between successive price changes. He applied a range of filter sizes with varying assumptions about transactions costs and concluded that there was evidence of exploitable serial persistence and as such a characterization of the Rotterdam spot market for gas oil as being fundamentally inefficient was appropriate.¹⁷ Perhaps of more practical relevance, Bohi and Toman (1987)¹⁸ provide a general framework to analyze the inter-relationships among spot and futures prices as well as inventories for NYMEX's No.2 heating oil in the context of dynamic market conditions. Utilizing the rational expectations paradigm, they are able, among other things to point to the critical importance of the

¹⁶(...continued)
under different price schema. Also, such markets do not have mechanisms for standardizing the commodities traded or for aiding the price discovery process so that traders may trade on the basis of complete information.

¹⁷The earlier comments directed at Gjolberg's work also applies to Bird who, like Gjolberg constructs an analysis on rather dubious theoretical grounds. See in the above regard, Bird, W. "Continuity and Reversal in Oil Spot Price Movements" *Energy Economics*, April 1987, pp. 73-81.

¹⁸Bohi, D. and Toman, M. (1987); "Futures Trading and Oil Market Conditions" *Journal of Futures Markets*, Vol. 7 No. 2, pp. 203-221.

inter-connection between inventory demand and price behavior and the manner in which market performance is influenced by supply disturbances as well as inventory demand shocks.

Finally, Abken (1989)¹⁹ focused on the possibility of earning potential profits by constructing intra-market spreads on NYMEX's No.2 heating oil futures contract. He showed, among other things, by way of a simulation that an intra-market spread strategy which took into account the seasonal variation in futures prices may be able to realize some systematic returns conditional on transactions costs being fairly nominal.

This paper is intended to be a part of the same broad genre as the last two studies referred to above. Our primary departure is in our focus on the intermarket spread relationships among futures prices in the energy complex. We shall seek as part of our analysis to investigate the stochastic properties of the price relationships that underpin this market. Our purpose for undertaking such an investigation is to provide evidence on the theoretical adequacy of the martingale model as a reasonable characterization of futures prices in the NYMEX energy complex. In this regard, following

¹⁹Abken, P. (1989): "An Analysis of Intramarket Spreads in Heating Oil Futures" *Journal of Futures Markets*, Vol. 9 No. 1, pp. 77-86.

our introduction of some background material on the energy complex and the nature of the contracts that are defined on this complex, we describe the 321 crack spread and explain its calculation. Next we introduce a theoretical model of the generalized crack and thus establish the relevant theoretical underpinnings for the 321 crack. We then follow our exposition on the generalized crack with a section which introduces the notion of weak form testing of market efficiency. Next, we apply standard regression techniques to the price series of the individual markets to ascertain if they behave like martingales. Our final section begins with an application of covariance analysis techniques to the determination of the weak form efficiency properties of the 321 crack spread and concludes with an application of the theory of cointegrated processes and Error correction Modeling to the problem of investigating the weak form properties of the individual price series in the energy complex.

1.2 The Refined Oil Complex and its Underlying Futures Contracts

Perhaps the best way to attempt a description of the refined oil complex (ROC) is to recognize at the outset that technically speaking this complex is not represented by a just a few domestically familiar products. In fact there are over 2000 hydro-carbon based products that are fractionally distilled from a given crude feedstock. For example, there are products such as the low temperature light end leaded and unleaded gasolines, the middle level distillates which include diesel and heating oils (the so-called #2 oil) and kerosene (or #1 oil), the residuals like lubricating oils, wax, coke, and asphalt, the liquified petroleum gases (LPG) such as propane and butane and the petrochemical sub-complex which includes ethylene, propylene, benzene etc. Since approximately some 95% of a typical barrel of low sulfur (sweet) crude is represented by the unleaded and leaded gasolines (26 % respectively), #2 and #1 middle distillates (26 %) and the #6 residuals (18 %) the ROC is generally accepted as being defined around these products.

Before we give some description of the futures contracts that are currently traded domestically and internationally, it might be useful to give some historical contextualization of their emergence.

For many years, crude oil and refined petroleum products prices were characterized by a level of stability that was unlike that found in the prices of other commodities. Such a situation obtained because crude oil and ROC contracts were administratively set by a few very large vertically integrated domestic and international petroleum firms who set prices to maximize their individual profit functions often at the expense of the producing countries. By the mid 1970s, the situation changed dramatically when the Organization of Petroleum Exporting Countries (OPEC) nationalized the petroleum resources and facilities in their individual countries. With OPEC's assumption of control over the upstream sector of the hydrocarbon complex crude prices began to drift upwards as the cartel began implementing a strategy of systematically reducing crude liftings in order to reduce world supplies of crude and increase prices. The ensuing volatility of crude oil and ROC prices was soon followed by a disarticulation of crude and ROC markets which, up until the rise of OPEC, had been fully integrated and administered by the large petroleum majors. The decoupling of the crude and ROC markets signalled the end of an era of predictable and stable relationship between these two price groups with the effect of exposing refiners, producers and other ROC end-users to increased price risk thus making the idea of trading futures contracts defined on the energy complex increasingly appealing and viable.

Of the 2000 plus crude derivatives mentioned above only a very few-- unleaded gasoline, leaded gasoline, propane, heating oil and crude oil itself, have succeeded in becoming part of the current energy futures complex being traded on the three major domestic commodity exchanges--the Chicago Board of Trade (CBT), the New York Mercantile Exchange (NYMEX), and the New York Cotton Exchange (NYCE)-- and the International Petroleum Exchange (IPE) which is based in London. Since NYMEX has emerged as the major player in providing hedging opportunities for refiners and other energy market participants since it began trading heating oil (HO) futures back in November 1978 the descriptions that follow focus only on NYMEX's contracts . Currently, NYMEX has four major futures contract in its energy complex viz., heating oil (HO), crude oil (Cr), unleaded gasoline (UG) and propane (PR).

The NYMEX HO futures contract is based on a transaction unit of 1,000 barrels or 42,000 U.S gallons and sold at dollar quotes for ex-shore f.o.b delivery at New York Harbor. The contract is currently traded as far out as fifteen consecutive months thus allowing traders the opportunity of hedging positions over two two winter heating seasons. Trading typically ceases around the last week of the month preceding the contract maturity month but traders are permitted to close their open positions by taking reverse positions or by making

physical delivery or by the exchange of futures for physicals (EFP) (by which traders are able to make alternative delivery arrangements outside of NYMEX's contract specifications).

NYMEX's UG futures contract trades (as in the case of its HO contract) over fifteen consecutive months thereby accommodating hedging strategies stretching over two driving seasons. The contract's unit of account is 1,000 barrels and is priced in dollars per gallon for par delivery f.o.b at New York Harbor. Since its introduction the UG contract has seen spectacular increases in interest with trading having grown from a little over 23,000 contracts per month in 1986 to 253,000 contracts per month in 1988. In a fashion similar to the NYMEX's HO contract, the UG contract "comes off the board" around the last week of the month that precedes the delivery month but permits traders to close out positions by way of reverse trades or by wet delivery or by EFPs.

Like the previously discussed HO and UG contracts, the WTI crude contract is traded in 1,000 barrels and priced in dollars per barrel and deliverable par grade at Cushing, Oklahoma. Although the WTI crude contract is a relatively new feature in NYMEX's energy complex it has already risen to the status of being the U.S. bench mark crude trading at a premium over the other crudes. A cursory view of the NYMEX's trading records easily reveals the increasing popularity of the WTI

crude given that its current average volume of contracts (through June 1988) is well over 70 million barrels per day as compared with an average daily volume of 58 million for 1985. Open trading in this contract ends usually in the final week of the month preceding the contract delivery or spot month but traders are able to close out open positions either by reversing their positions or by wet delivery or by using EFPs.

The final item in the NYMEX energy complex is PR which trades in units of 1,000 barrels at prices denominated in dollars per gallon for a period of fifteen consecutive months delivery being accepted f.o.b in Mont Belvieu, Texas. Total volume traded to date is 12,167 contracts representing some 12.2 million barrels. As is the case for the other energy products traded by NYMEX the PR contract enters a non-open trade period in the last week of the month preceding the contract maturity month. At this time traders holding open positions in the contract are allowed to make settlement either by reverse trade or by wet delivery or by the use of EFPs.

1.3 Benefits of Energy Futures Markets

The continued existence of futures markets in the face of historical and contemporaneous detraction by critics points to the important contributions such markets continue to make to the trading of commodities in the context of general uncertainty and risk averting agent behavior. Futures markets which cater for contracts defined on the hydrocarbon complex are not unlike such markets that are constructed around other commodities. To be sure, most if not all of the arguments that are typically advanced to rationalize the relevance of futures markets at the general level apply *a fortiori* when one considers a commodity complex such as energy.

For the participants involved in all levels of the hydrocarbon complex these are particularly uncertain times given the political and military turbulence in major crude oil supply areas. Futures markets for crude oil and other products in the energy complex acting as information aggregating and centralizing mechanisms facilitate the public transmission of critical information about current and past prices and about

quantities of energy products bought and sold over a particular period of time. In addition, such markets have internal policing and enforcement apparatuses which help to ensure not only that solvency standards are met e.g., margin requirements-- but also that contracts that are traded meet strict quantity as well as quality criteria. Because of their centralization energy futures markets provide time and transactions cost economies by eliminating the need for traders to spend time in geographically seeking out each other and then investing further time haggling over contract rules and specifications.

Refiners typically enter into contracts to be supplied with crude oil at given prices without any firm idea of the prices for the refined products complex at the time of marketing. Contracting for crude oil supplies before the beginning of the refinery run is but one step in the production process. Next the crude has to be transported to the refinery and then processed into the refined product complex. Finally, the finished complex is then transported to storage facilities to await marketing. During the time it takes the refiner to complete the processing run and position the complex for

delivery the product price regime may move against him and expose him to losses. It is in the context of such price volatility that the crucial role that energy futures market play in providing some degree of price insurance for agents having long positions in crude and/or the complex of refined petroleum products becomes more evident. In such cases the agent who is long the complex and fearing price exposure is able to hedge this price risk by selling the complex short in the futures market and closing out the position by going long in the same market.

Chapter 2

2.1 The Industry 321 Crack Spread

The 321 crack or "paper refinery" spread is an inter-market spread that is designed to hedge refined products by crudely imitating the operations of a typical refinery. In this regard, this particular intermarket spread becomes in essence the financial analog of the technical business of cracking hydrocarbon molecules into a very narrow range of refined products. In terms of the algebra of its calculation, the crack at its most general level is defined as

$$N_{t-j} = \sum_{i=1}^n F_{t-j,t} X_i - r_{c,t-j} C \quad (1)$$

where N_{t-j} is the crack as viewed from time period $t-j$, $F_{t-j,t}$, X_i , $r_{c,t-j}$ and C represent respectively the futures price of the i th refined product as of time $t-j$ for delivery in time t , the actual futures position taken by the trader in refined products, the cash price at $t-j$ for the WTI crude and the actual initial acquisition of crude for refining. As the formula indicates, calculating the crack spread or netback

simply amounts to summing over the (revenue) values of the refined products and netting out the acquisition cost of the crude input.

The speculator's fundamental intent in trading the crack is to benefit from the price differentials that arise from the futures prices for crude oil, heating oil and unleaded gasoline. To execute such a spread trade the trader would, for example, buy a given number of heating oil contracts perhaps in the winter period while covering this open position by simultaneously selling unleaded gas futures deliverable for the same months anticipating that due to winter demand the price for heating oil contracts would be pressured upwards while that for unleaded gas would move in the opposite direction due to the seasonal fall off in driving. When the season changes the trader reconstitutes his spread trade by buying unleaded gas with the expectation of a seasonal increase in summer driving pressuring gasoline prices upward and selling heating oil as the demand for space heating diminishes due to the arrival of warmer weather.

Traders sometimes reverse the crack. This would tend to be the strategy to use when the price relationships between

crude and the refined products become inverted. Thus when the trader sees that the price of crude is consistently higher than that of the refined products and if he thinks that this price relationship has peaked and will reverse in the short run he may decide to go short on crude and long on refined products anticipating an opportunity to lock in the profit arising from selling high priced crude and buying low priced refined products.

In the business of trading the energy complex there are a wide number of intermarket spread strategies that are often used by "paper refiners" as well as real refiners. Included in these spread rules is the so-called 50/50 spread where the trader includes an equal number of gas and heating oil contracts to hedge against his crude acquisitions. There is also the 10-7-3 and the 2-1-1 spread in which, respectively, the trader crack spreads 10 crude contracts against seven No.2 heating oil and three unleaded gas contracts or two crudes against one No.2 heating oil and one unleaded gas contract.

Of the several crack spreads available to the industry the one that has gained large acceptance as the primary crack

spread device is the so-called 321 contract. The 321 contract basically sells (buys) two unleaded gasoline and one No. 2 heating oil contract for every three crude contracts bought (sold). Thus the actual calculation of the 321 crack spread proceeds by pricing out the revenues implied by two Unleaded Gasoline contracts plus one NO. 2 Heating Oil contract and subtracting the cost of three WTI Crude Oil contracts from the combined refined products revenues. In implementing this particular "paper refinery" rule the trader contracts for the delivery of his refined products approximately one month after taking delivery of his crude stocks since this is the average time the typical refiner requires to process the average crude into the various refined products.

Chapter 3

3.1 Towards a Theory of the Generalized Crack Spread.

The above chapter introduced the notion of the 321 crack spread and provided an explanation of its calculation as well as some motivation for its existence. Although it seems clear that as a trading rule the 321 crack spread is popular among traders in the energy industry, its microeconomic foundations are not very clear. As a consequence of the absence of any obvious theoretical underpinnings, this section of the paper will attempt to provide some theoretical rationale for the 321 crack. We proceed by making two simplifying assumptions to facilitate the exposition. The first being that agents are risk neutral i.e., they are indifferent between the expected payoff on a risky position and its certainty equivalent. Secondly, the further assumption of the absence of basis risk is made thus guaranteeing the equivalence of the spot price and the futures price at maturity in time period t .

We begin by modelling the representative refiner's objective function in order to derive the necessary (first order) conditions for constrained maximization as well as the class of implied restrictions on the futures prices in the

energy complex.

Let us introduce the notation for the relationships appearing in this section:

t : a horizon date when (i) the futures contract defined on the energy complex matures. (ii) the cash market meets to transact trades around the Refined oil complex (ROC).

K_t^i : i th refiner's expected net revenue relation at t for the trading period t to $t+1$.

p_t : cash market price for the ROC at time t .

v_t : variable input prices at time t .

r_t : fixed input prices (essentially crude) at time t .

$f_{j,t}^r$: futures price for the j 'th contract at t maturing at r

Y_i : i 'th output.

q_t^i : futures position of the i th refiner at time t constructed around contracts for ROC that are scheduled to mature in $t+1$.

$C^i(Y_i, r_t, v_t)$: the i th refiner's cost function for a given level of output Y and defined with respect to fixed and variable input prices r and v respectively.

With this notation established let us begin by laying out the refiner's decision. Thus, let us consider a representative refiner who at time $t-j$ decides upon an energy complex to produce for marketing at time t . Let the production relationship that maps crude oil and other inputs into the refined oil complex (ROC) be described by the non-stochastic production function $Y_i = \phi(Cr, X_i)$ where X_i is the i 'th variable input (e.g., labor). Corresponding to this production function is the non stochastic cost function $C_i(Y_i, r_t, v_t)$ which is defined with respect to a given level of throughput Y_i and a given profile of input prices. The refiner's net revenue relation at time t can therefore be expressed as:

$$K^i_t = \sum_{j=1}^m P_{i,t+j} Y_{i,t} - C^i(Y_i, r_t, v_t) + \sum_{j=1}^m (F^r_{j,t} - F^r_{j,t+1}) q_{it} \quad (2)$$

$$\text{where, } q_{it} = S_i + Y_i, \text{ for all } i=1, \dots, m \quad (3)$$

and S_i is his speculative position parameter which is defined as the difference between his futures position and his output. The refiner's objective is that of maximizing the net value of his production and hedged position subject to his cost outlays. As a first step in this maximization problem, let us

assume that the first m of the refiner's outputs are unhedgeable and the other $m+1$ to n outputs are hedgeable. Then we can reformulate (2) as

$$K_t^i = \sum_{j=1}^m F'_{j,t} Y_{j,t} + \sum_{j=m+1}^n P_{j,t+1} Y_{j,t} + \sum_{j=1}^m (F'_{j,t} - F'_{j,t+1}) S_j - C^i(Y_{i,t}, r_t, v_t) \quad (4)$$

now by allowing $m=n$ (i.e., defining all outputs as hedgeable) and then differentiating (4) with respect to the i 'th output we recover the following first order condition for a maximum,

$$K_{Y_i}^i = F'_{i,t} - C_i(Y_{i,t}, r_t, v_t) = 0 \quad \forall i = 1, \dots, n \quad (5)$$

Equation (5), in addition to being the first order condition for an interior maximum is also both interpretable as the short run competitive equilibrium at which factors are receiving their marginal revenue product and as the point at which the hedger is able to separate his production and

futures decisions.²⁰ The long run analog of (5) is also easily derived by first noting that in the long run firms are making zero abnormal profits and therefore equilibrium is at the point where total revenue equates total cost. Second, making use of the fact that the cost function is linearly homogeneous in all input prices and applying Euler's Theorem (i.e., finding the marginal cost for each input) the long run competitive equilibrium is seen to be,

$$K^I = \sum_{i=1}^n F'_{i,t} Y_{i,t} - C'_r(.) r_t - C'_v(.) v_t = 0 \quad (6)$$

Equations (5) and (6) represent not only two separate and distinct notions of economic efficiency but in addition provide the refiner with the means of imposing objective constraints on the price relations at the time when he is concerned about his marketing and hedging decisions. Moreover, the strength of these equilibrium conditions lie in their generality and in their ability to explicitly accomodate specific price constraints such as the 321 crack. To establish this claim, let us begin by assuming that crude oil constitutes the single input into the refinery process which after a one period lag turns out a complement of perfectly

²⁰See, Anderson, R. W., and Danthine, Jean-Pierre (1983) "Hedger Diversity in Futures Markets" The Economic Journal, vol. 93, pp. 375.

substitutable refined products. Let α_i be the share of crude going into production of the i 'th output. It follows then that

$$C^i(Y_{it}, r_t, v_t) = \sum_{i=1}^n Y_{it} r_t = \sum_{i=1}^n \alpha_i = Cr \quad (7)$$

so that the long run equilibrium condition in (6) implies,

$$0 = \sum_{i=1}^n F'_{it} - \sum_{i=1}^n Y_{it} r \quad (8)$$

and upon making the relevant substitutions and multiplying through by r we recover,

$$0 = \sum_{i=1}^n \alpha_i F'_{it} - r \sum_{i=1}^n \alpha_i \quad (9)$$

The underlying relationship expressed in (9) is that of the the Generalized Crack. In words, the generalized crack requires a linear combination of futures and spot prices weighted by the sum of the crude input fractions used in the refining process to be exactly equal. Given (9) it is relatively simple to show for example, that the 321 crack price relation (and others like it) is a special case of the more Generalized Crack relationship. In this regard, let us assume that $n=2$, $\alpha_1=1/3$ and $\alpha_2=2/3$, then (9) resolves to

$$F'_{1t} + 2F'_{2t} - 3r_t = 0 \quad (10)$$

which is the popular industry 321 crack relation²¹.

The formulation in (10) as we have seen, states the relationship existing among the futures prices for the refined products and the spot price for crude. What now follows is a brief analysis of the restrictions implied by (10) specifically on the futures prices of the products in the oil complex. We begin by noting that the futures trading activities of hedging and speculating have at least one area of commonality and that is their dependence upon an underlying expectations hypothesis about price movements. The typical assumption about futures prices is, that conditional on some publicly available information set they should be unbiased predictors of the maturity date prices. Using (10) and the following keys,

- (1) F'_{10} ---the futures price of crude for delivery at time τ ,
- (2) F'_{11} ---the futures price of heating oil for delivery at τ ,
- (3) F'_{12} ---the futures price of unleaded gas for delivery at τ ,

²¹In the context of petro-production and refining given the relatively high short run fixed operational costs, the assumption that the industry is always in long run equilibrium is somewhat tenuous; a far better claim in this regard would be to assume the existence of short run equilibrium.

as well as the Samuelsonian (1965)²² Expectations Hypothesis (which is elaborated upon in a later section in this paper), the above linear 321 crack futures price relations for contracts at maturity is easily represented as,

$$F^{*+1}_{1t} + 2F^{*+1}_{2t} - 3F^r_{0t} = E_t(F^{*+1}_{1t} + 2F^{*+1}_{2t} - r_t) \quad (11)$$

and implies that the 321 contract should follow a martingale stochastic process.

Until now, we have assumed the most general characterization for the cost function in our development of the refiner's equilibrium conditions. At this point, let us assume that the underlying production technology is linearly homogeneous in inputs, then, this being the case, it is possible to represent the cost function in a form that is multiplicatively separable in the levels of the output and input prices. Thus, consider the following cost function for $n=m=2$,

$$C(Y_1, Y_2, r_t, v_t) = [\alpha_1 Y_1 + \alpha_2 Y_2 + \alpha_3 (Y_1 Y_2)^{1/2}] (\beta_1 r_t + \beta_2 v_t) \quad (12)$$

on this basis we can define the refiner's optimality position at the time of the futures contract maturity and assuming conditions of long run equilibrium, in the following manner,

²²Samuleson, Paul (1965) "Proof etc. " *ibid.*

$$K_{t+1}^1 = F^{r+1}_{1t} Y_1 + F^{r+1}_{2t} Y_2 = [\alpha_1 Y_1 + \alpha_2 Y_2 + \alpha_3 (Y_1 Y_2)^{1/2}] (\beta_1 r_t + \beta_2 v_t) \quad (13)$$

defining $\Theta = (Y_1/Y_2)$ and performing the necessary algebra (13) reduces to the following linear restriction in output and input prices for a given value of Θ ,

$$(F^{r+1}_{1t} \Theta + F^{r+1}_{2t}) = (\alpha_1 \Theta + \alpha_2 + \alpha_3 \Theta^{1/2}) (\beta_1 r_t + \beta_2 v_t) \quad (14)$$

Now, from the above general restrictions on input and output prices required for competitive equilibrium, the Expectations Hypothesis can be easily derived. As a first step, let us rewrite (14) as,

$$F^{r+1}_{1t} \Theta + F^{r+1}_{2t} = (\alpha_1 \Theta + \alpha_2 + \alpha_3 \Theta^{1/2}) \beta_2 (\delta_3 r_t + v_t) \quad (15)$$

where $\delta_3 = (\beta_1/\beta_2)$. Again, after performing the necessary algebra (15) reduces to,

$$\delta_1 F^{r+1}_{1t} + \delta_2 F^{r+1}_{2t} - \delta_3 r_t = v_t \quad (16)$$

with $\delta_1 = \Theta / (\alpha_1 \Theta + \alpha_2 + \alpha_3 \Theta^{1/2}) \beta_2$ and $\delta_2 = 1 / (\alpha_1 \Theta + \alpha_2 + \alpha_3 \Theta^{1/2}) \beta_2$. Invoking the Expectations Hypothesis and noting that the futures price for crude at time t deliverable in τ is $F^r_{0,t}$ (16) becomes ,

$$\delta_1 F^{r+1}_{1t} + \delta_2 F^{r+1}_{2t} + F^r_{0t} = E_t \quad v_t \quad (17)$$

Equation (17) under the assumption of long run equilibrium conditions and a cost function that is multiplicatively separable in outputs and the level of input prices is the Generalized Crack relation at time t . The essence of (15) is that the Generalized Crack at time t represents an unbiased prediction of the expected refining costs (with the exception of crude).

3.2 Summary And Conclusions

There are several important points to note here. First, it is clear from our analysis that intermarket spreads like that of the 321 crack spread are not whimsical devices although they may have been stumbled upon through a process of trial and error. Such spread strategies reflect traders attempts at speculating away any profit opportunities that may exist across the energy complex. The essential advantage of our exposition is its reliance upon a fundamental microeconomic framework to construct the decision making process of a refiner or speculator operating in the context of a risky environment. Thus our framework specifically highlights the various choice sets (including product mix and hedging strategies) as well as resource constraints which would typically confront the rational agent and indicates how the agent in his optimization efforts would reconcile his concern for risk with his production and hedging plans. The important point to note in the above regard is that given the fact that the 321 crack spread is a competitive equilibrium result of an optimization process then our empirical analysis of its stochastic (qua efficiency) properties should be basically validating. Second, in contrast to the 321 crack rule, our framework of analysis enables us to recover equilibrium conditions (as in (9)) which are empirically

testable depictions of the typical agent's maximizing behavior. Thus when we examine the 321 crack for weak form efficiency properties we are assured that our analysis can be reasonably constructed upon some theoretical priors about the series' likely stochastic behavior. Finally, in laying out the theory of the Generalized Crack there are no requirements that the formulation be constrained by the specificity of any functional form for the production or cost relationships. As we have noted above, this is not true for the model underlying the 321 crack spread which implicitly assumes that the refined oil outputs are linearly related to the input set.

Chapter 4.

4.1 Data Description and Summary Statistics

Before we turn to an investigation of the efficiency implications of the industry 321 crack spread and its implied rate of return we shall first attempt to develop a statistical understanding of the character of the futures prices that form the basis of this return.

Given that futures price quotes are the outcomes of speculative decisions that are conditioned on currently available information we would expect the underlying profit opportunities in these prices to be randomly distributed around zero if we were to abstract from transactions and other such costs. This is obviously the case since the existence of any systematic profit opportunities in trading the crack would cause market participants to reconstitute their trades in order to appropriate the profit opportunities for themselves.

Our investigation of the time series properties of the individual futures prices of the products comprising the energy complex proceeded on the basis of the assumption that the observations in each price series represented the realization of a an unknown stochastic process. This enabled

us to utilize standard time domain analytical tools like the autocorrelation and partial autocorrelation functions in our characterization of the underlying process generating the individual price series. Our investigation based on these methods returned mixed results. For example, our examination of the undifferenced form of the futures prices for crude revealed the existence of a very strong positive trend in the autocorrelation function with the correlation coefficient for lags 1 through lag 11 being significantly different from zero at the 5% level of significance. In addition to the above, the coefficient estimates of the partial autocorrelation function was dominated by the significant lag one estimate of .97684 while the others were all not significantly different from zero at the 5% level. Putting the information contained in the autocorrelation and the partial autocorrelation functions together it was clear that the futures prices for crude oil was nonstationary in the levels and was best described as being a random walk with a statistically significant drift parameter.

A similar examination of the autoregressive representation of the futures price series for unleaded gas revealed evidence of nonstationarity. The autocorrelation function was similarly characterized by a strong positive trend in the lag coefficients and, as in the case of the crude

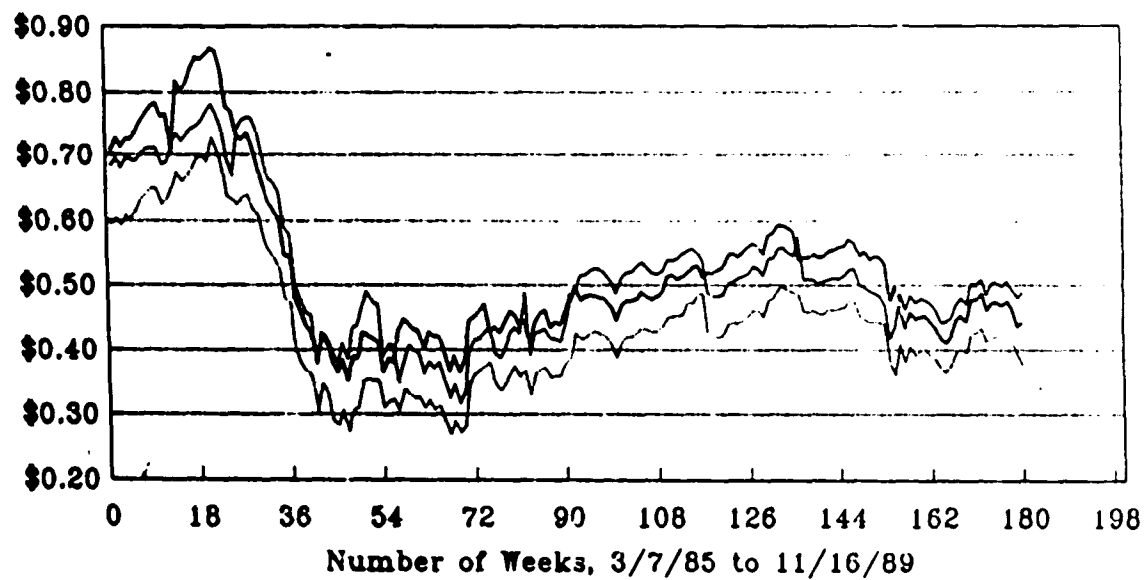
price series, the partial autocorrelation function was dominated by one significant correlation estimate at lag one. The combined evidence of the partial autocorrelation and the autocorrelation functions indicated that the unleaded gas futures price series was also best represented by the random walk process.

Our analysis of the futures price series for heating oil revealed autocorrelational and partial autocorrelational patterns that were quite similar to those obtained in the case of crude oil and unleaded gasoline. Although it was quite apparent that heating oil prices were nonstationary the series did not appear to be a simple random walk as was the fact for crude oil and unleaded gasoline. These latter series were clearly random walks as evidenced by the fact that a CHI-SQUARED test of the residuals from the estimation of their autoregressions in first differences indicated that they were white noise. In the case of heating oil, the series showed evidence of being integrated of order one and border line stationary only when estimated in the logged first difference.

Next, for the three year interval of 1986 to 1989 a simple levels plot of the per gallon Wednesday settlement futures prices for unleaded gas, No 2. heating oil and WTI was done and this revealed a few interesting facts about their behavior. First, for most of 1985 the price paths of crude oil

and the refined products heating oil and unleaded gas tended to parallel each other as they tracked upward in tandem. Over this period however, the settlement price for heating oil was consistently above that of the other two products followed by that for unleaded gas. By late fall of that year the prices for all three products peaked and thereafter declined secularly for some forty three weeks in the case of crude and heating oil respectively and for some seventy six weeks in the case of unleaded gasoline. By the early spring of 1986 (in the case of the WTI crude and heating oil contracts) and the midsummer of that year the NYMEX settlement prices for all three products began a serially persistent rise but failed to reach the levels that they had separately attained during the earlier part of 1985. Figure 1 below gives a graphical depiction of the early rise, peak, decline and then persistent increase in the Wednesday settlement prices of the crude oil and two of its downstream products.

Wednesday Settlement Prices
Heating Oil, Unleaded Gas,
& WTI Crude Oil



— Unleaded Gas — Heating Oil Crude Oil

Figure 1

Although Figure 1 does give some indication of the volatility of the prices in this particular energy complex, the pattern is not unambiguous given the fairly long periods of declining prices followed by that of a fairly long period of slowly rising prices. To get a better picture of whether or not such prices were volatile in the sample period in question we have calculated the sample variance of percentage changes in the daily prices sampled on the Wednesday of each successive week. The picture that emerges is indeed one of price volatility over the sample period. Table I below depicts the volatility of futures prices based upon the sample variance. Looking at the evidence in intra commodity terms we see a similar pattern among all three items and that is a, relatively high degree of volatility as we move from the January 1986 maturity to that of July 1986. This initial high volatility persists for all products through to the January 1987 maturity month then falls for the July 1987 contract only to continue rising through both the January 1988 and July 1988 contract months.

**Table I. Volatility of Weekly NYMEX Energy Futures Prices
as Measured by the Variance of Price Relatives.**

Contracts	Variance
UL GAS	
JAN86	6.15
JUL86	51.56
JAN87	58.70
JUL87	3.96
JAN88	13.63
JUL88	14.74
NO.2 HEAT_OIL	
JAN86	18.41
JUL86	36.16
JAN87	31.05
JUL87	5.47
JAN88	8.32
JUL88	14.65
CRUDE OIL	
JAN86	7.67
JUL86	59.22
JAN87	39.34
JUL87	5.20
JAN88	15.22
JUL88	19.45

We have used daily price data for the No.2 Heating Oil, WTI Crude Oil and Unleaded Gas contracts traded at NYMEX to construct a rate of return measure for the typical industry crack spread-- the 321 contract. Since there appears to be growing evidence that the distribution of returns calculated from daily prices is non-stationary from day to day partly

because of holiday and weekend effects²³ we decided to sample the Wednesday's settlement price of each contract used in the construction of the standard crack spread.

As we have indicated earlier, the time that it takes the average refiner to process crude into refined products is approximately one month. This one month production interval requires the crack spread series to be formed with the crude leg of the spread being constructed on contracts that are deliverable at least one month prior to those for refined products. Thus, in the construction of our series representing the industry's 321 contract we began by sampling the Wednesday's WTI settlement price starting with the January 1986 contract and continuing through all the intervening maturity months to the December 1988 contract. In a similar fashion, but starting one month later, we began our price series construction for the refined product prices by sampling the Wednesday's settlement price for the NYMEX No.2 Heating Oil and Unleaded Gas contracts beginning with the February 1986 contracts and continuing through to the January 1989 contracts.

²³See Gibbons, M. R. and Hess, P. (1988): "Day of the Week Effects and Asset Returns," *Journal of Business*, Vol. 54, No.4, pp. 579-596.

At this point it should be noted that although officially the NYMEX's crude contract is supposed to 'go out' for some eighteen months while the unleaded gas and NO.2 heating oil contracts are supposedly tradeable over a fifteen month period actual price and volume histories for these contracts indicate that such trading intervals are more often than not hardly utilized by traders particularly in the early period of the contract offerings. The difference in contract lengths and the variability of the extent of actual price data even for series with identical trading lives made it necessary for us to align our sample by reducing price series for individual contracts to the lowest common denominator which in most cases was the unleaded gas contract, (which unlike WTI crude and the NO. 2 heating oil contract was only introduced to the NYMEX energy complex in 1986).

Once the prices were sampled and the respective series were formed we turned next to the construction of the industry 321 contract crack spread or netback. The crack spread was constructed by calculating the revenue derived from one heating oil and two unleaded gasoline contracts and subtracting the acquisition cost for three crude contracts.

Having constructed the netback in this fashion it was very obvious that we had not yet come up with a series that could be characterized as a being a time series. One reason

why this was the case was the presence of severe overlapping of contract months throughout the three year interval. We considered among an alternative number of ways to obtain a consistent time series which would reduce the problem of contract overlapping as well the structural discontinuities that such overlapping tended to generate.

Of these alternative methods one possibility was to organize the "time series" by stacking similar months over the three year interval beginning with the crack values for January 1986 through January 1988 then continuing with the February 1986 value and so on.

A second alternative approach was to use only the crack values calculated from the last three months of any given contract in the three year period. Thus for example, this approach could take the January 1986 crude contract along with the February 1986 heating oil and unleaded gas contracts and calculate the crack but basing such calculation only on price quotations from the last three months of the contracts' trading lives.

A third approach to this time series construction problem (and the one that we decided upon) was to sample the contract maturity months at six month intervals. In sampling every six months from the constructed crack spread data we selected the

January and July maturity months for each year in the three year interval and through this method we were able to align our data with a minimum of overlapping and discontinuities. Table IIA, Table IIB and Table IIC respectively give some indication of the nature of the problem surrounding the developing of a coherent and consistent time series of the crack spread and the device employed by us a solution.

In Tables IIA, IIB and IIC, we depict the crack spread combination contract 'month', the relevant price quotation date and the percentage rate of return (which is defined as the ratio of the calculated 321 netback to the acquisition cost of crude times 100) for all the contracts traded over the January 1986 to July 1988 period²⁴. Presented in this fashion, one can easily see the how the contract overlapping problem was minimized by the device of sampling at the January and July points in each year. Since there is a very low incidence of contract overlapping these series were used as the basis of our evaluation of the efficiency properties of the industry's 321 crack spread.

²⁴We have chosen not to show the complete table indicating the extent of the overlapping problem given the fact that it is several pages long. We are quite willing to make this data available to anyone who has an interest in seeing these numbers.

TABLE IIA: Aligned 321 Rate of Return

Contract Month	Quote Date	% Rate of Return
JAN86:FEB86	07/03/85	16.265
JAN86:FEB86	07/10/85	16.915
JAN86:FEB86	07/17/85	16.479
JAN86:FEB86	07/24/85	16.017
JAN86:FEB86	07/31/85	16.446
JAN86:FEB86	08/07/85	14.701
JAN86:FEB86	08/14/85	13.984
JAN86:FEB86	08/21/85	13.575
JAN86:FEB86	08/28/85	13.069
JAN86:FEB86	09/04/85	13.512
JAN86:FEB86	09/11/85	13.706
JAN86:FEB86	09/18/85	13.146
JAN86:FEB86	09/25/85	9.261
JAN86:FEB86	10/02/85	13.132
JAN86:FEB86	10/09/85	13.867
JAN86:FEB86	10/16/85	13.793
JAN86:FEB86	10/23/85	14.348
JAN86:FEB86	10/30/85	12.489
JAN86:FEB86	11/06/85	12.885
JAN86:FEB86	11/13/85	15.783
JAN86:FEB86	11/20/85	11.273
JAN86:FEB86	11/27/85	12.607
JAN86:FEB86	12/04/85	13.276
JAN86:FEB86	12/11/85	13.281
JAN86:FEB86	12/18/85	11.219
JUL86:AUG86	11/06/85	17.735
JUL86:AUG86	11/13/85	17.253
JUL86:AUG86	11/20/85	17.422
JUL86:AUG86	11/27/85	20.161
JUL86:AUG86	12/04/85	17.922
JUL86:AUG86	12/11/85	19.408
JUL86:AUG86	12/18/85	17.952
JUL86:AUG86	01/08/86	19.505
JUL86:AUG86	01/15/86	19.531
JUL86:AUG86	01/22/86	19.851
JUL86:AUG86	01/29/86	19.834
JUL86:AUG86	02/05/86	23.300
JUL86:AUG86	02/12/86	24.581
JUL86:AUG86	02/19/86	22.579
JUL86:AUG86	02/26/86	23.721
JUL86:AUG86	03/05/86	26.961
JUL86:AUG86	03/12/86	22.213
JUL86:AUG86	03/19/86	24.754
JUL86:AUG86	03/26/86	34.800
JUL86:AUG86	04/02/86	31.720
JUL86:AUG86	04/09/86	30.285

TABLE IIB: ALIGNED 321 RATE OF RETURN

Contract Month	Quote Date	% Rate of Return
JAN87:FEB87	04/30/86	23.183
JAN87:FEB87	05/07/86	18.838
JAN87:FEB87	05/14/86	25.760
JAN87:FEB87	05/21/86	25.653
JAN87:FEB87	05/28/86	24.254
JAN87:FEB87	06/04/86	20.897
JAN87:FEB87	06/11/86	23.283
JAN87:FEB87	06/18/86	26.346
JAN87:FEB87	06/25/86	25.660
JAN87:FEB87	07/02/86	25.943
JAN87:FEB87	07/09/86	26.087
JAN87:FEB87	07/16/86	25.239
JAN87:FEB87	07/23/86	22.125
JAN87:FEB87	07/30/86	24.438
JAN87:FEB87	08/06/86	19.201
JAN87:FEB87	08/13/86	18.320
JAN87:FEB87	08/20/86	17.059
JAN87:FEB87	08/27/86	18.125
JAN87:FEB87	09/03/86	14.119
JAN87:FEB87	09/10/86	17.256
JAN87:FEB87	09/17/86	19.292
JAN87:FEB87	09/24/86	19.139
JAN87:FEB87	10/01/86	20.413
JAN87:FEB87	10/08/86	17.859
JAN87:FEB87	10/15/86	19.859
JAN87:FEB87	10/22/86	29.119
JAN87:FEB87	10/29/86	20.297
JAN87:FEB87	11/05/86	19.101
JAN87:FEB87	11/12/86	18.607
JAN87:FEB87	11/19/86	19.233
JAN87:FEB87	11/26/86	18.515
JAN87:FEB87	12/03/86	18.639
JAN87:FEB87	12/10/86	17.237
JAN87:FEB87	12/17/86	17.649
JAN87:FEB87	12/24/86	23.677
JAN87:FEB87	12/31/86	15.988
JUL87:AUG87	01/07/87	20.418
JUL87:AUG87	01/14/87	20.648
JUL87:AUG87	01/21/87	19.331
JUL87:AUG87	01/28/87	19.564
JUL87:AUG87	02/04/87	19.810
JUL87:AUG87	02/11/87	19.603
JUL87:AUG87	02/18/87	20.578
JUL87:AUG87	02/25/87	22.124
JUL87:AUG87	03/04/87	20.808
JUL87:AUG87	03/11/87	20.109

TABLE IIC: ALIGNED 321 RATE OF RETURN

Contract Month	Quote Date	% Rate of Return
JAN88:FEB88	04/08/87	17.822
JAN88:FEB88	04/15/87	17.358
JAN88:FEB88	04/22/87	18.602
JAN88:FEB88	04/29/87	18.216
JAN88:FEB88	05/06/87	17.868
JAN88:FEB88	05/13/87	17.433
JAN88:FEB88	05/20/87	18.403
JAN88:FEB88	05/27/87	17.990
JAN88:FEB88	06/03/87	17.403
JAN88:FEB88	06/10/87	17.377
JAN88:FEB88	06/17/87	16.921
JAN88:FEB88	06/24/87	16.608
JAN88:FEB88	07/01/87	16.119
JAN88:FEB88	07/08/87	15.417
JAN88:FEB88	07/15/87	15.505
JAN88:FEB88	07/22/87	14.062
JAN88:FEB88	07/29/87	14.590
JAN88:FEB88	08/05/87	14.133
JAN88:FEB88	08/12/87	16.106
JAN88:FEB88	08/19/87	13.115
JAN88:FEB88	08/26/87	13.482
JAN88:FEB88	09/02/87	13.099
JAN88:FEB88	09/09/87	13.448
JAN88:FEB88	09/16/87	14.051
JAN88:FEB88	09/23/87	12.812
JAN88:FEB88	09/30/87	14.037
JAN88:FEB88	10/07/87	13.509
JAN88:FEB88	10/14/87	13.905
JAN88:FEB88	10/21/87	13.540
JAN88:FEB88	10/28/87	13.534
JAN88:FEB88	11/04/87	13.926
JAN88:FEB88	11/11/87	15.123
JAN88:FEB88	11/18/87	14.561
JAN88:FEB88	11/25/87	14.331
JAN88:FEB88	12/02/87	13.908
JAN88:FEB88	12/09/87	11.102
JAN88:FEB88	12/16/87	15.360
JAN88:FEB88	12/23/87	26.896
JUL88:AUG88	01/06/88	17.380
JUL88:AUG88	01/13/88	18.598
JUL88:AUG88	01/20/88	17.538
JUL88:AUG88	01/27/88	18.928
JUL88:AUG88	02/03/88	17.847
JUL88:AUG88	02/10/88	17.055
JUL88:AUG88	02/17/88	18.842
JUL88:AUG88	02/24/88	17.346

In order to develop an understanding of the underlying statistical character of the 321 crack spread we exhibit in Table III some summary descriptive statistics for each cross section.

Table III. Descriptive Statistics of NYMEX's 321 Crack Spread

Variable	N	Sum	Mean	S.E.	σ^2	σ	MIN	MAX
JAN86	25	345	13.8	0.36	3.32	1.82	9.26	16.92
JAN87	36	756	21.0	0.61	13.23	3.64	14.12	29.12
JAN88	38	592	15.6	0.44	7.23	2.69	11.10	26.90
JUL86	31	769	37.5	1.10	37.50	6.12	17.25	37.58
JUL87	25	457	18.3	0.61	9.34	3.06	8.25	22.12
JUL88	25	445	17.8	0.35	3.14	1.77	15.81	25.06

Notes: (i) σ^2 and σ are the variance and standard deviation respectively.
(ii) S.E. is the standard error of the mean and N is the number of observations in each cross section.
(iii) MIN and MAX respectively represent the minimum and the maximum values in each cross section.

From Table III a picture of relatively extreme volatility in the 321 crack spread emerges on both an *inter* as well as an *intra* year basis. Thus inter year, we witness with respect to the range, in the case of the January contracts, an initial increase of 96% for January 1987 over January 1986 followed by a relatively moderate increase of 5.3 % for January 1988 over January 1987. Unlike the January crack range changes, the July crack range changes were all downwards. Thus for the July 321 crack spreads our inter year analysis indicates that the July

1987 percent change over July 1986 was a decrease of 31.7 % followed by 33.43 % for July 1988 over July 1987. Looking at changes in the range from an intra year perspective we observe a similar picture of volatility. Thus we find that the percent change in the range for the January 321 crack over that of July for the year 1986 was 165%. Similarly, for the years 1987 and 1988 respectively, the percent change in the range intra year for the same months was -7.5% and -41.55%. This picture of inter and intra year volatility in the 321 crack is also reflected in the percent changes in the variance of the respective crack cross sections. In this regard, we observe that inter year, the January 1987 percent change in the variance was 298% followed by -45.6% for January 1988 over January 1987. With respect to the July cracks, the percent change in the variance for July 1987 over July 1986 was -75% followed by -66.7% for July 1988 over July 1987. Viewed from an intra year angle, again the same picture of volatility emerges as it is revealed that the variance of the July 1986 crack with respect to that for January 1986 represents an increase of 1029%. This is followed by the variance changes for the July 1987 crack over that of January 1987 and the July 1988 crack over that of the January 1988 of respectively, -29.7% and -56.9%.

Our above statistical description of the 321 crack cross sections is obviously useful in enabling us to get a better summary indication of the statistical characteristics of the crack series. However to get some understanding of the stochastic character of these series requires that we utilize the same frequency domain methods discussed earlier in our investigation of the individual prices series. This will enable us to among other things, get a fix on the stationarity properties as well as the lag structure of the individual crack series. Based on analysis of the autocorrelation and partial autocorrelation functions for each cross section we are able to make the following characterizations concerning the individual crack contracts:

- (i) the January 1986, 1987 and 1988 crack contracts are all covariance stationary and are best characterized by an autoregressive process in one lag (AR(1));
- (ii) the autocorrelation function of the July 1986 crack contract is characterized by a significant trend in the lag coefficients combining this with the fact that the partial autocorrelation function is dominated by a significant spike at lag one leads to the conclusion that this series is best described as being a random walk.
- (iii) the July 1987 although dominated by a significant correlation at lag one in both the autocorrelation and the partial autocorrelation functions appeared to be a simple AR(1) process.
- (iv) the July 1988 showed no significant correlations at any lag and thus appeared to be a white noise process.

Chapter 5.

5.1 Market Efficiency and Weak Form Tests of Energy Product Markets .

We have introduced the notion of "market efficiency" above without any attempt at explaining its meaning. Since much of what follows in the next several chapters of this study surrounds this very idea, we shall explore it from both an intuitive as well as a more technical angle.

In the context of a multigood market (such as the energy futures market is) the existence of an equilibrating price vector is predicated upon the simultaneous existence of a conditioning set of current and past prices to be used by investors to form forecasts of the future path of prices. The conditioning set therefore provides a measure on the realization of next period's future's prices. To the extent that agents construct their trades in an informationally rational manner then to that extent the price outcomes of their market interactions will be efficient. Put somewhat differently, if prices in a given market are not informationally efficient then the astute trader can systematically realize abnormal returns to his position. If we

however assume that the systematic existence of surplus profit opportunities will draw other rational agents to attempt to appropriate such profits for themselves then it appears quite reasonable to conclude that such abnormal profit opportunities will be bid away by traders acting in their own self interest. Market efficiency therefore at its most fundamental level implies efficiency with respect to the conditioning information set. Market outcomes which leave opportunities for individual agents to secure abnormal profits therefore point to a market structure that is inefficient with respect to the information set.

Samuelson (1965) provides one of the earliest succinct statements on the notion of market efficiency as it relates to the theory of stochastic processes. Assuming that $f^I_{t,T}$ is a sequence of price quotes at t for a futures contract maturing at time T and $p_{t,T}$ is a sequence of price quotes for the corresponding spot contract Samuelson establishes the Martingale property of futures prices as

$$f^I_t = E(f^{I-1}_{t+1} \mid p_t, p_{t-1}, \dots) \quad (18)$$

where E is the expectation operator and (2) states that the current futures price of a futures contract deliverable in T periods, is equal to the current conditional mathematical expectation of the price of the futures contract next period. The obvious importance of (18) insofar as weak form test of the efficiency of the 321 crack is concerned lies not only in the fact that it indicates that in the context of speculative markets the expected change in the futures price of a contract deliverable at a given time in the future is zero but, perhaps more importantly, there should also be a unit root in the autoregressive representation of the crack. In practical terms this means that any n 'th order autoregression of the individual futures price series should recover parameter estimates not significantly different from one at lag one with all other estimated coefficients being not significantly different from zero at lags greater than one.

5.2 Weak Form Tests of Efficiency in The NYMEX Energy Complex: Applications of Dickey-Fuller Analysis.

Perhaps the simplest and most direct way of implementing weak form tests of market efficiency in the context of the energy futures market is to examine the autoregressive representation of the individual price series to see if their lag one parameters are bounding toward one in magnitude. In fact, this is precisely what we did. We estimated two separate AR(3) regressions for price series derived from the January and July contracts for the period 1986 through 1988. In what follows immediately below, we lay out the general specification of the model estimated and then proceed to report the results of the estimations:

$$\text{Janpr}_{i,t}^j = \beta_0 + \beta_1 \text{Janpr}_{i,t-1}^j + \beta_2 \text{Janpr}_{i,t-2}^j + \beta_3 \text{Janpr}_{i,t-3}^j + \epsilon_{it} \quad (19)$$

$$\text{Julpr}_{i,t}^j = \beta_0 + \beta_1 \text{Julpr}_{i,t-1}^j + \beta_2 \text{Julpr}_{i,t-2}^j + \beta_3 \text{Julpr}_{i,t-3}^j + \epsilon_{it} \quad (20)$$

where $\text{Janpr}_{i,t}^j$ and $\text{Julpr}_{i,t}^j$ are the period t futures price quote for the January and July contracts from the j th year respectively with the following indexes applying:

$$j = 1986, \dots, 1988$$

$$t = 1, 2, \dots, n, \text{ weeks}$$

$$i = \text{HO, UG, CR}$$

A cursory analysis of the results set out in Table IV, Table V and Table VI reveals that the stochastic behavior of futures prices in the individual markets are strikingly similar. In all three markets, the price series are dominated by the lag one coefficient which, based on a t -statistic at a level of confidence of 5 % appears to be significant. Again, in all three markets the parameter estimates at lags greater than one do not seem to be different from zero at a 5 % level of significance. These results seem therefore to be in keeping with the Samuelsonian unbiased expectation hypothesis on the basis of which the best forecast of current prices is last period's price with the information contained in the periods before the last being irrelevant to the price forecast problem. Stated directly, since the estimates at lag one are statistically significant and dominate the coefficient estimates of all other lags greater than one both in terms of magnitude as well as statistical significance it therefore would appear that the stochastic behavior of the individual futures price series is not inconsistent with the market efficiency paradigm.

Table IV. Regression Estimates for AR(3) Heating Oil Prices

Contract	Varb.	Parameter	Estimate	S.E	t_ratio
JAN86	HO ^a	β_0	0.196	0.113	1.73
JAN86	HO	β_1	0.634	0.232	2.73
JAN86	HO	β_2	0.287	0.268	1.07
JAN86	HO	β_3	-0.166	0.239	-0.70
JUL86	HO	β_0	0.387	0.019	1.99
JUL86	HO	β_1	0.688	0.186	3.70
JUL86	HO	β_2	0.403	0.226	1.81
JUL86	HO	β_3	-0.198	0.178	-1.11
JAN87	HO	β_0	0.137	0.761	1.79
JAN87	HO	β_1	0.769	0.188	4.10
JAN87	HO	β_2	0.082	0.234	0.35
JAN87	HO	β_3	-0.163	0.198	-0.83
JUL87	HO	β_0	0.470	0.067	0.71
JUL87	HO	β_1	1.052	0.247	4.26
JUL87	HO	β_2	-0.362	0.357	-1.01
JUL87	HO	β_3	0.217	0.273	0.80
JAN88	HO	β_0	0.138	0.085	1.64
JAN88	HO	β_1	0.825	0.181	4.56
JAN88	HO	β_2	0.070	0.301	0.23
JAN88	HO	β_3	-0.148	0.237	-0.62
JUL88	HO	β_0	0.138	0.079	1.75
JUL88	HO	β_1	0.806	0.219	3.67
JUL88	HO	β_2	0.081	0.256	0.32
JUL88	HO	β_3	-0.192	0.211	-0.91

a: HO represents the NYMEX NO. 2 Heating Oil Contract.

Table V. AR(3) Regression Estimates For NYMEX Unleaded Gasoline Futures Prices

Contract	Varble	Parameter	Estimate	S.E.	t_ratio
JAN86	UG ^b	β_0	0.195	0.091	2.14
JAN86	UG	β_1	1.280	0.220	5.82
JAN86	UG	β_2	-0.434	0.371	-1.17
JAN86	UG	β_3	-0.118	0.268	-0.44
JUL86	UG	β_0	0.414	0.025	1.67
JUL86	UG	β_1	0.809	0.188	4.30
JUL86	UG	β_2	0.366	0.243	1.51
JUL86	UG	β_3	-0.276	0.180	-1.54
JAN87	UG	β_0	0.697	0.065	1.07
JAN87	UG	β_1	0.667	0.189	3.54
JAN87	UG	β_2	0.231	0.224	1.03
JAN87	UG	β_3	-0.064	0.194	-0.33
JUL87	UG	β_0	0.123	0.081	1.51
JUL87	UG	β_1	1.115	0.237	4.71
JUL87	UG	β_2	-0.393	0.344	-1.14
JUL87	UG	β_3	0.046	0.261	0.18
JAN88	UG	β_0	0.276	0.072	0.38
JAN88	UG	β_1	0.781	0.180	4.34
JAN88	UG	β_2	0.195	0.257	0.76
JAN88	UG	β_3	-0.033	0.219	-0.15
JUL88	UG	β_0	0.118	0.079	1.49
JUL88	UG	β_1	0.706	0.225	3.14
JUL88	UG	β_2	0.231	0.244	0.95
JUL88	UG	β_3	-0.181	0.212	-0.86

b: UG represents NYMEX's Unleaded Gasoline.

Table VI. AR(3) Regression Estimates For NYMEX's WTI Crude Futures Price Series.

Contract	Variable	Parameter	Estimate	S.E.	t_ratio
JAN86	CR ^c	β_0	0.152	0.07	2.05
JAN86	CR	β_1	0.996	0.22	4.52
JAN86	CR	β_2	-0.105	0.31	-0.34
JAN86	CR	β_3	-0.122	0.21	-0.58
JUL86	CR	β_0	0.036	0.02	1.81
JUL86	CR	β_1	0.675	0.21	3.29
JUL86	CR	β_2	0.281	0.24	1.17
JUL86	CR	β_3	-0.079	0.19	-0.42
JAN87	CR	β_0	0.435	0.04	1.00
JAN87	CR	β_1	0.935	0.20	4.68
JAN87	CR	β_2	0.046	0.26	0.18
JAN87	CR	β_3	-0.101	0.20	-0.51
JUL87	CR	β_0	-0.020	0.05	-0.36
JUL87	CR	β_1	1.038	0.23	4.49
JUL87	CR	β_2	-0.148	0.34	-0.44
JUL87	CR	β_3	0.163	0.26	0.62
JAN88	CR	β_0	0.031	0.06	0.53
JAN88	CR	β_1	1.218	0.18	6.75
JAN88	CR	β_2	-0.249	0.35	-0.72
JAN88	CR	β_3	-0.040	0.28	-0.14
JUL88	CR	β_0	0.123	0.06	1.91
JUL88	CR	β_1	0.844	0.21	3.94
JUL88	CR	β_2	0.206	0.21	0.99
JUL88	CR	β_3	-0.358	0.18	-2.01

c: CR represents the NYMEX Crude Oil Contract.

Claims of weak form efficiency of these energy commodity markets cannot yet be made since, as Fuller²⁵ in his seminal work on statistical time series has shown that, to the extent that the lag one coefficient is in the region of unity then standard asymptotic distribution theory, given its presumption of stationarity in the underlying series, does not apply to the validation of hypotheses irrespective of the sample size. Dickey and Fuller²⁶ in a series of articles established statistically correct procedures to test the null hypothesis of $\beta=1$ against the alternative that it is not. These statistical procedures proceed by way of the "unit root test" which seeks to establish whether a pth-order autoregressive (AR) process,

$$P_t^j = \beta + \sum_{i=1}^p \phi_i P_{t-i}^j + \epsilon_t ,$$

(P_t^j being any arbitrary price series) (21)

²⁵Fuller, W. A. (1976) Introduction to Statistical Time Series. New York: John Wiley & Sons.

²⁶Dickey, David A., & Wayne A. Fuller, (1979) "Distribution of the estimators for autoregressive time series with a unit root" Journal of the American Statistical Association Vol., 74, pp 427-431.

Dickey, David A., & Wayne A. Fuller, (1981) "Likelihood ratio statistics for autoregressive time series with a unit root" Econometrica vol., 49, pp 1057-1072.

is stationary--i.e., possess roots of the lag polynomial $\phi(B) = (1 - \phi_1 B - \dots - \phi_p B^p)$ located outside the unit circle²⁷. The essence of the test is the regressing of the first difference of the underlying series on a constant, and an AR(1) term as well as a term representing the first difference of the AR(1) term which is intended to capture any systematic dynamics in the error structure. The null hypothesis asserts that the series contains a unit root i.e., $\rho = 1$ (that is to say that departures away from the mean of the series become permanent in nature) thus implying that the coefficient on the AR(1) term should be indistinguishable from zero. To see this, consider the following AR(1) process defined on an arbitrary futures price series

$$F_t = \alpha + \rho F_{t-1} + \phi \Delta F_{t-1} + \epsilon_t \quad (22)$$

subtracting F_{t-1} from both sides of (22) yields the following,

$$\Delta F_t = \alpha + \beta_1 F_{t-1} + \phi \Delta F_{t-1} + \epsilon_t \quad (23)$$

²⁷In this regard, see Granger, C. W, and Newbold, P. (1977) *Forecasting Economic Time Series*. New York: Academic Press.

where $\beta_1 = \rho - 1$. It is clear therefore that β_1 in (23) is simultaneously an estimate of $(\rho - 1)$ as well as a test of the unit root restriction with the closer β_1 approaches zero the more credible the claim of a unit root in the autoregressive representation becomes.

In addition to developing the statistical procedures to test for the presence of unit roots in the autoregressive representation of nonstationary time series, Dickey and Fuller (1979a) and more recently Hasza and Fuller²⁸ have also established the appropriate parametric values derived from a new large sample distribution theory for the empirical implementation of the tests²⁹.

Based upon the above large sample theory we examined our earlier regression results for the three pairs of futures

²⁸Hasza, D.P & Fuller, W. A. (1979): "Estimating for Autoregressive Processes with Unit Roots" *Annals of Statistics*, vol. 7 pp 1106-1120.

²⁹Note that the relevant test statistic is similar to the standard t ratio in that it is simply the ratio of the estimated coefficient to its standard error. The essential difference in the current case is that under the maintained hypothesis the statistic is no longer distributed as " t " but follows the new tau " τ " distribution. Estimates of the critical values or critical percentiles of τ - τ are reported in Fuller (1976), p 373.

price series for the presence of unit root tests in their autoregressive representations to see whether they were random walks and therefore supportive of weak form market efficiency. We present our results of the Dickey-Fuller tests in Table VII Table VIII and Table IX. The values of the Dickey-Fuller τ_μ statistic furnish no evidence against the null hypothesis that these autoregressions are characterized by unit roots. From Fuller (1976, p 373) the critical percentile values for a one-tailed 5 % level of significance test of the maintained hypothesis with $25 \Rightarrow N < 50$ is given in Table X with the domain of rejection defined by smaller (more negative) values of τ_μ .

Table VII. Dickey-Fuller Tests for Unit Roots in the Auto-Regressive Representations of the Levels of Heating Oil Futures Prices.

Contract	N ^a	α^*	β_1^*	ϕ^*
JAN86_HO	25	0.16 (0.10)	-0.20 (0.13)	-0.21 (0.21)
JUL86_HO	31	0.03 (0.02)	-0.09 (0.04)	-0.21 (0.18)
JAN87_HO	36	0.11 (0.07)	-0.25 (0.16)	0.02 (0.19)
JUL87_HO	25	0.07 (0.06)	-0.14 (0.12)	0.17 (0.26)
JAN88_HO	38	0.12 (0.08)	-0.22 (0.14)	0.06 (0.20)
JUL88_HO	25	0.12 (0.08)	-0.26 (0.17)	-0.07 (0.21)

a: N=Sample size.

Note: Standard errors are in parenthesis.

Table VIII. Dickey-Fuller Tests for Unit Roots in the Autoregressive Representations of the levels of WTI Crude Futures Prices.

Contract	N ^a	α^*	β_1^*	ϕ^*
JAN86_CR	26	0.11 (0.07)	-0.17 (0.11)	0.20 (0.21)
JUL86_CR	30	0.03 (0.18)	-0.11 (0.04)	-0.19 (0.18)
JAN87_CR	36	0.03 (0.04)	-0.10 (0.12)	0.00 (0.19)
JUL87_CR	25	-0.00 (0.05)	0.01 (0.11)	0.02 (0.25)
JAN88_CR	38	0.03 (0.05)	-0.06 (0.12)	0.28 (0.20)
JUL88_CR	26	0.08 (0.07)	-0.20 (0.17)	-0.24 (0.18)

^a: N=Sample Size.

Note: Standard errors are in parenthesis.

Table IX. Dickey-Fuller Tests for Unit Roots in the Autoregressive Representations of Unleaded Gasoline Futures Prices.

Contract	N ^a	α^*	β^*	ϕ^*
JAN86_UG	25	0.15 (0.09)	-0.21 (0.12)	0.50 (0.21)
JUL86_UG	31	0.03 (0.02)	-0.08 (0.05)	-0.07 (0.18)
JAN87_UG	36	0.07 (0.06)	-0.17 (0.15)	-0.16 (0.19)
JUL87_UG	25	0.13 (0.07)	-0.25 (0.13)	0.35 (0.22)
JAN88_UG	38	0.02 (0.06)	-0.05 (0.12)	-0.17 (0.20)
JUL88_UG	25	0.10 (0.07)	-0.22 (0.16)	0.21 (0.20)

a: n=Sample Size.

Note: Standard errors are in parenthesis.

Table X. Dickey-Fuller Summary Results of Random Walk vs. Covariance Stationarity in the Autoregressive Representation of Energy Futures Prices.

Contract	ρ	t_ρ	CV ^a	Decision
JAN86_HO	0.80	-1.49	-3.00	ACCEPT H_0
JUL86_HO	0.90	-2.19	-2.98	ACCEPT H_0
JAN87_HO	0.75	-1.61	-2.97	ACCEPT H_0
JUL87_HO	0.86	-1.18	-3.00	ACCEPT H_0
JAN88_HO	0.78	-1.63	-2.96	ACCEPT H_0
JUL88_HO	0.74	-1.58	-3.00	ACCEPT H_0
JAN86_CR	0.83	-1.65	-3.12	ACCEPT H_0
JUL86_CR	0.89	-2.48	-2.99	ACCEPT H_0
JAN87_CR	0.91	-0.79	-2.97	ACCEPT H_0
JUL87_CR	0.98	0.09	-3.00	ACCEPT H_0
JAN88_CR	0.94	-0.52	-2.96	ACCEPT H_0
JUL88_CR	0.80	-1.20	-3.12	ACCEPT H_0
JAN86_UG	0.80	-1.21	-3.00	ACCEPT H_0
JUL86_UG	0.92	-1.70	-2.98	ACCEPT H_0
JAN87_UG	0.83	-1.16	-2.97	ACCEPT H_0
JUL87_UG	0.75	-1.97	-3.00	ACCEPT H_0
JAN88_UG	0.95	-0.40	-2.96	ACCEPT H_0
JUL88_UG	0.88	-1.39	-3.00	ACCEPT H_0

a:CV are Critical values for $N>25<50$ are linear interpolations.

Since all of the cross sectional r_t values are well to the left of the critical region the essential conclusion to be drawn from these several results is that the levels of the futures price for all three commodity contracts in the energy complex do not appear to have stable --i.e., stationary-- univariate autoregressive representations. This thus provides fairly strong support for our earlier cross-sectional regression results suggesting that these markets are all characterized by martingale processes and are therefore weak form efficient.

Chapter 6.

6.1 Weak Form Efficiency and the NYMEX 321 Crack: Tests and Analysis

In most of the preceding sections, we have investigated the stochastic and (therefore) efficiency properties of the individual futures price series in the energy complex and we have, for the most part, been able to establish their general consistency with the attributes of weak form market efficiency. However, at the practical level, speculators and hedgers involved in these markets are not particularly concerned with the behavior of individual prices but instead focus primarily on the overall interrelationship among them. These agents plan their trading strategies on the basis of their expectations of the behavior of the crack. In this regard then, an understanding of whether the weak form efficiency properties observed in the individual commodity markets carry over monotonically to the 321 crack relationship becomes of central importance.

6.2 Covariance Modelling of The Crack

Although our investigation of the autoregressive representation of the six crack return series had revealed that they all (with one exception) appeared to be best described as AR(1) processes, we specified AR(3) models for our estimation to ensure whiteness of the residuals and to increase the generality of our specification.

To estimate the AR(3) models we decided to pool over the cross-sectional and time series attributes of the sample. There are a number of fundamentally important and compelling reasons why resorting to such a device could prove useful.

First, since pooling essentially entails stacking each cross sectional series upon the other, then it is clear that such stacking significantly increases the number of degrees of freedom available for model estimation and enables us to make inferences about the population as opposed to the sample parameters.

Second, since pooling effectively augments the sample space, then by this measure (and within certain limits) it also results in an enhancement of the precision of the parameter estimates.

Third, given that cross-sectional specific unobservable effects may be correlated with other explanatory variables and time specific unobservable effects may also be correlated with these same explanatory variables thus producing biased estimates this source of bias is often better controlled for in a panel estimation or pooling framework where cross-equation restrictions can be easily enforced to mitigate this problem.

Finally, there is the fact that contracts of different maturity dates are often traded contemporaneously thereby creating problems of mutual correlation among cross-sections and loss of parameter efficiency.

Pursuing the issue of contemporaneous correlation of residuals across equations more closely, we calculated the cross sectional correlations of the residuals from the AR(3) regression of the futures prices in the individual markets. These error correlations (shown in Table XI) below generally reveal a systematic pattern of contemporaneous correlation of errors across cross-section. Thus, for example, the January 1986 price errors two out of the three pairs of correlations have Pearson correlation coefficients greater than .40 ; in the case of January 1987 all correlations are greater than .75; the January 1988 correlations indicate that two out of

the three coefficients are .79 while the other one is .45. For July, the Pearson correlation estimates are somewhat different from that of January. Thus, the July 1986 and July 1988 error correlation coefficients indicate that two out of three are fairly "weak" with the last one being greater than .90. The July 1987 Pearson correlations of the residuals are all relatively very high with the smallest being .76 and the largest being .89.

Table XI. Cross-Correlation Coefficients of Energy Futures Prices Regression Residuals^a.

JAN86	CR_RES	HO_RES	UG_RES
CR_RES	1.00	0.43	0.80
HO_RES		1.00	0.19
UG_RES			1.00
JAN87			
CR_RES	1.00	0.80	0.85
HO_RES		1.00	0.76
UG_RES			1.00
JAN88			
CR_RES	1.00	0.79	0.79
HO_RES		1.00	0.45
UG_RES			1.00
JUL86			
CR_RES	1.00	-0.13	-0.08
HO_RES		1.00	0.94
UG_RES			1.00
JUL87			
CR_RES	1.00	0.80	0.76
HO_RES		1.00	0.89
UG_RES			1.00
JUL88			
CR_RES	1.00	-0.04	-0.05
HO_RES		1.00	0.96
UG_RES			1.00

a: Note: CR_RES, HO_RES and UG RES respectively represent crude oil, heating oil and unleaded gasoline AR(3) price regression residuals.

Parameter estimation in the context of data characterized by both time and cross-sectional attributes encounters problems not only of contemporaneous correlation of cross-sectional errors but in addition problems having to do with heteroscedastic cross-sectional variances. In our present case, there are the volatility effects due to the narrowing of the basis as contract maturity approaches and similar effects due to the existence of seasonal shocks to demand and supply for heating oil and motor fuels. It is precisely as a consequence of the above mentioned problems that our approach to the estimation of futures prices in the energy complex proceeds by way of a nested model whose generality provides not only for corrective measures for the issues of contemporaneous correlation and heteroscedasticity but also for specific tests of whether or not the individual cross-sections can reasonably be pooled.

To motivate our estimation of the nested model of the crack rate of return we shall at this point give a brief description of the underlying econometrics involved. In this regard, consider the N ($=6$) cross sections across T time periods discussed above. If we represent the i 'th cross sectional regression as,

$$Y_{i,t} = \alpha_i + \beta_i X_{i,t} + \mu_{i,t} \quad (24)$$

where $t=1,2,\dots,T$ is a linear time index, Y is the crack rate of return, X is a matrix of variables (including lags on Y) and μ is a vector of Gaussian error parameters respectively capturing the regression intercept and slope. Embedded in equation (24) are the following sub-models:

$$Y_{it} = \alpha + \epsilon_i \quad (25.1)$$

$$Y_{it} = \alpha_i + \epsilon_{it} \quad (25.2)$$

$$Y_{it} = \alpha + \beta X_{it} + \epsilon_{it} \quad (25.3)$$

$$Y_{it} = \alpha_i + \beta X_{it} + \epsilon_{it} \quad (25.4)$$

$$Y_{it} = \alpha + \beta_i X_{it} + \epsilon_{it} \quad (25.5)$$

$$Y_{it} = \alpha_i + \beta_i X_{it} + \epsilon_{it} \quad (25.6)$$

where equation (25.1) is simply an ANOVA suggesting the absence of group or regressor effects on the variation of the crack return. Equation (25.2) models the influence on the crack of group effects only i.e. it amounts to the fixed effects dummy variable model without regressor influence. Expression (25.3), in restricting the crack return to variation from a single fixed effect and the influence of regressors amounts to the familiar OLS model. Model (25.4) is

of the "error-components" type which, in addition to admitting the influence of group and regressor effects on the variation of the crack, further posits the cross sectional intercepts α_{it} to be independent random variables with mean α_{-1} and variance σ^2_{α} and the slope coefficients to be fixed parameters. The final equation, (25.5) permits both regressor and group effects to determine the variation of the crack series without any prior constraints upon the character of the slope or intercept parameters; it therefore is the least restrictive of all the models in the above system.

Since in the above section we have mentioned the fixed effects dummy variable model and the error component model we shall at this point give a further explication of the underlying econometrics involved in both cases. For both the fixed effects and the error component models the estimation proceeds by pooling or stacking the data for each cross-section as in the following example,

$$Y = X\beta + \mu$$

(26)

	.				
	Y_{11}		X_{11}		μ_{11}
	Y_{12}		X_{12}		μ_{12}
	.		.		.
	.		.		.
	Y_{1T}		X_{1T}		μ_{1T}
	.		.		.
	.		.		.
$Y =$	Y_{1T+k}	$X =$	X_{1T+k}	$\mu =$	μ_{1T+k}
	.		.		.
	.		.		.
	Y_{i1}		X_{i1}		μ_{i1}
	Y_{i2}		X_{i2}		μ_{i2}
	.		.		.
	.		.		.
	Y_{it}		X_{it}		μ_{it}
	.		.		.
	.		.		.
	Y_{iT+k}		X_{iT+k}		μ_{iT+k}
	.		.		.
	.		.		.
	Y_{NT+k}		X_{NT+k}		μ_{NT+k}

where Y, X and μ are all $NT \times 1$ vectors. Note that the slope and intercept parameters can, in this formulation, be modelled as being specific to each cross section or can be constrained to be uniform over each cross section. In the case of the fixed effects model, apart from the explicit assumptions made about the parameters that are to be estimated there are other quite as important implicit assumptions that are made as a matter of course with respect to the disturbance term. In particular, the essence of these assumptions are:

- (i) $E(u_{it}) = 0$ for the i th cross section and time t
- (ii) $E(u_{it}u_{is}) = 0$ for $t \neq s$ and all i implying an absence of any autoregressive properties in the disturbance term.
- (iii) $E(u_{it}^2) = \sigma^2 \forall i$ and t
- (iv) $E(u_{it}u_{jt}) = 0 \forall i \neq j$, thus indicating the non-existence of contemporaneous correlation of the error term across cross sections.

We note at this juncture that there are a number of difficulties which ensue when the fixed effect or covariance method of pooling is employed for model estimation. First, the individual effects of the covariates are often crowded out by the introduction of dummy variables designed to allow the

intercept term to capture time and cross sectional effects³⁰. Second, employing dummy variables offers no guidance in identifying the specific variables that are responsible for the random perturbations associated with each cross section. Third, such use of dummy variables often tends to explain some of the variation in the disturbance term but without providing any special understanding of the effects of the explanatory variables on the dependent variable. Finally, the use of dummy variables to capture fixed effects as part of the covariance approach to pooling requires the estimation of separate intercept terms thus imposing a relatively substantial loss of vital degrees of freedom and as a consequence diminishes model efficiency.

Given the theoretical and practical difficulties that are associated with the covariance approach to pooling it became clear that an alternative method had to be developed. One way of approaching the development of an alternative approach to pooling cross sectional and time series attributes is to realize at the outset that the inclusion of dummy variables to capture cross sectional and time effects by the intercept term represents an admission of some degree of ignorance about the behavior of the model. Since such uncertainty is usually best

³⁰ Moriarity, M. (1975) "Cross Sectional, Time Series Issues in the Analysis of Marketing Decision Variables", *Journal of Marketing Research*, vol.12, (May) pp. 142-50.

captured by the disturbance term, a different approach to pooling which explicitly takes the error structure into account was developed³¹.

The so-called error components model begins with the idea that the optimal way to capture ignorance in a regression model is to incorporate it into the error term where its underlying structure may be identified and interpreted. In this regard, one immediate difference between this technique and that of the covariance approach is in its treatment of ignorance and random effects. Whereas the covariance technique would sweep such time and individual random disturbances into separate intercepts to be estimated (at a substantial cost of degrees of freedom) the error components method would treat these effects as two normally and independently distributed (NID) random variables requiring estimation of only their first two moments. The essential details of the error

³¹ Balestra P, and Nerlove M, (1966) "Pooling Cross-Section and Time Series Data in the Estimation of a Dynamic Model: The Demand for Natural Gas," *Econometrica*, vol. 34, no.4, pp. 585-612.

Maddala, G.S. (1969) "The use of Variance Components Models in Pooling Cross Section and Time Series Data," *Econometrica*, vol. 39, no. 2, pp. 341-358.

Maddala, G.S. and Nerlove M, (1971) "Further Evidence on the Estimation of Dynamic Economic Relations from a Time Series of Cross Sections," *Econometrica*, vol. 39, no. 2, pp. 359-381.

components model is set out as follows³²:

$$Y_{it} = \alpha + \beta X_{it} + \epsilon_{it} \quad (27)$$

$$\epsilon_{it} = u_i + v_t + w_{it} \quad (28)$$

where $u_i \sim \text{NID}(0, \sigma_u^2)$ represents the extent to which the i th cross sectional's unit intercept is different from that of the general sample (the so called "between district effect").

$v_t \sim \text{NID}(0, \sigma_v^2)$ captures the period specific (the so called within district effects") and cross sectional invariant effects.

$w_{it} \sim \text{NID}(0, \sigma_w^2)$ expresses the remaining effects assumed to vary over both time and cross sectional dimensions.

³²Note that the Error Components model, given its explicit consideration of the separate time and cross section disturbance effects seems particularly relevant to the problem of modeling the crack rate of return given:

(i) the problem of contract overlap and the contemporaneous correlation across contract maturities (i.e., cross sections),

(ii) the presence of time dependent variances that tend to increase with time to contract maturity.

In addition to the above, the error components are assumed to be uncorrelated with each other and are not autocorrelated. This means that,

$$\text{Cov}(u_i, v_t) = \text{Cov}(u_i, w_{it}) = \text{Cov}(v_t, w_{it}) = 0$$

$$\text{Cov}(u_i, u_j) = 0 \quad i \neq j$$

$$\text{Cov}(v_t, v_{t'}) = 0 \quad t \neq t'$$

$$\text{Cov}(w_{it}, w_{jt}) = 0 \quad i \neq j$$

$$\text{Cov}(w_{it}, w_{it'}) = 0 \quad t \neq t'$$

$$\text{Cov}(w_{it}, w_{jt'}) = 0 \quad i \neq j, t \neq t'$$

Estimation of the error components model proceeds in a manner akin to the weighted least squares method since each observation is weighted in an inverse proportion to its variance. The actual application of the weights is performed using a two step Zellner method³³ since the variances of the error components are not known a priori. In stage one of the estimation process, OLS is run on the entire pooled sample space with the purpose of recovering the fitted residuals for use in calculating sample estimates of the variance components. Stage two proceeds by taking the calculated sample variances to obtain generalized least squares (GLS) estimates of $\beta = (X' \Omega^{-1} X)^{-1} (X' \Omega^{-1} Y)$.

³³Zellner, A. (1962) "An efficient Method of Estimating Seemingly Unrelated Regressions and Tests for Aggregation Bias", Journal of the American Statistical Association vol., 57, pp. 348-368.

6.3 Empirical Results

Having laid out the general econometric underpinnings of our nested model and its sub-models we turn now to the results of the estimation of equation (25). We note that the actual specification of equation (25) was as follows,

$$\text{Net}_{it} = \beta_0 + \beta_1 \text{Net}_{t-1} + \beta_2 \text{Net}_{t-2} + \beta_3 \text{Net}_{t-3} + \epsilon_{it} \quad (29)$$

where Net represents the crack or netback and from one to six separate constants and from zero to three slope parameters were estimated depending upon the model in question.

The evaluation of the claims of the nested sub-models proceeds by way of the following F test with the summary results reported in Table XII :

$$F_{calc} = ((SSR_R - SSR_U) / (DF_R - DF_U)) / (SSR_U / DF_U) \quad (30)$$

where SSR_R and SSR_U are the sum of squared residuals for the constrained and the unconstrained models respectively and DF_R and DF_U relate respectively to the degrees of freedom for the constrained and the unconstrained models.

Table XII. Nested Model Results.

Variable Means					
GROUP	SIZE	NET	NET1	NET2	NET3
****	163	18.67	18.71	18.71	18.80
JAN_86	22	13.43	13.63	13.83	13.97
JUL_86	28	25.61	25.42	25.14	24.97
JAN_87	33	20.87	21.16	21.02	21.18
JUL_87	22	18.01	18.51	18.91	19.11
JAN_88	35	15.37	15.13	15.19	15.38
JUL_88	23	17.77	17.45	17.43	17.43

UNCONDITIONAL ANOVA (NO REGRESSORS)

SOURCE	VARIATION	DF	MEAN SQUARE
BETWEEN	2522.15	5	504.43
WITHIN	1963.05	157	12.50
TOTAL	4485.20	162	27.69

OLS MODEL (NO GROUP EFFECTS)

VARIABLE	COEFF.	S.E.	t_RATIO
NET1	0.6637	0.088	7.56
NET2	0.0287	0.106	0.27
NET3	0.2529	0.093	2.72
CONST	0.9619	0.776	1.24

FIXED EFFECTS MODEL

t_RATIO	VARIABLE	COEFF.	S.E.
6.58	NET1	0.5956	0.091
0.04	NET2	0.0041	0.105
2.45	NET3	0.2287	0.093
1.98	β_{01}	2.0366	1.027
2.77	β_{02}	4.6579	1.679
2.35	β_{03}	3.3318	1.419
1.93	β_{04}	2.5323	1.314
2.62	β_{05}	2.7766	1.060
2.68	β_{06}	3.2941	1.229

ERROR COMPONENTS MODEL

t_RATIO	VARIABLE	COEFF.	S.E.
1.825	CONST.	1.8593	1.02
7.158	NET1	0.6329	0.09
0.177	NET2	0.0185	0.10
2.644	NET3	0.2447	0.09

VARIANCE COMPONENT ESTIMATES

Variance Component for the i 'th cross section	$\sigma_{\epsilon}^2 = 0.43$
Variance Component for the time series	$\sigma_{\epsilon}^2 = 0.0$
Variance Component for the combined error	$\sigma_{\epsilon}^2 = 5.95$

We begin by testing the hypothesis implied by (25.1)-- that the cross-sectional means of the crack series are identical to the population mean, there being no cross-sectional specificities that are not entirely due to random occurrences. The alternative hypothesis is implied by (25.2) which posits the claim that there are impact effects on the population mean of the crack series that are cross-sectionally specific. Given that the calculated F statistic of 40.3 exceeds the 5% critical F of 2.29 the null hypothesis of (25.1) vs (25.2) cannot be accepted and thus we conclude that there appears to be specific systematic group effects impacting on the crack series that cannot be considered as mere random occurrences.

Our second test of hypothesis relates to another implication of (25.1) and that is, there are no regressor effects on the crack series. Our alternative hypothesis of the presence of regressor effects on the variation of the crack series is set out in (25.3). Based on the application of the F test to the above null hypothesis the calculated F gives a value of 192.2 and since this number exceeds the 5% level of significance critical F of 2.68 we are unable to accept the null hypothesis and we therefore conclude that there are indeed regressors effects in addition to fixed effects influencing the variation of the crack series.

The final implication of (25.1) is that there are no joint regressor and group effects influencing the systematic variation of the crack series. We contrast this null hypothesis with an alternative one contained in sub-model (25.4) which states that there are both group as well as regressor effects determining the systematic variation of the crack. Calculating the relevant F for 8 restrictions and 154 degrees of freedom yields a value of 74.9 which when contrasted to the 5 % critical F value of 1.96 implies a rejection of the null claim of no joint effects.

Embedded in expressions (25.2) and (25.3) respectively are two hypotheses. The first of these, contained in (25.2) implies the claim that the crack series is only influenced by group effects and not by any regressor effects. Testing this maintained hypothesis at the 5 % critical level with an F test gives a calculated F of 58.5 against a critical F of 2.68 and thus suggests a rejection of the null hypothesis and a conclusion that there are indeed regressor effects on the variation of the crack series. The second hypothesis is implied by (25.3) where the claim is advanced that although there may be regressor effects which could operate on the crack series there are no corresponding group effects with any influence on this series. Again we employ a 5 % F test to statistically evaluate this assertion whereupon we find that the calculated F of 1.89 is less than the critical F of 2.29

thus implying that we cannot reject the null hypothesis that only regressor effects are relevant for the modeling of the crack series.

Our final hypothesis tests are concerned with establishing whether the cross-sectional coefficients are statistically different from one another on the hand, and on the other, whether the intercepts are capable of being considered as random variables with cross-sectional specific attributes. In this regard, one such claim is given by (25.3) vs (25.4) where the implication of the Null hypothesis is that the coefficients for the slopes and intercepts are respectively identical across cross-sections. This claim is evaluated by first estimating an OLS model of the pooled cross-section series. Next, to accommodate the alternative hypothesis we ran a covariance pooled regression with binary dummies for the individual fixed effect and with the individual slopes constrained to be identical across cross-sections. Using the SSR values recovered from these regressions and imposing the appropriate degrees of freedom and restrictions, we obtain a calculated F with the value 1.8. Since the critical value for $F_{5,154}$ is approximately 2.29 we are unable to reject the maintained hypothesis that the cross-sectional slope and intercept parameters are equal across cross-sections i.e., we cannot reject the claim that a single OLS is appropriate in this context.

A second hypothesis test arising from concerns about the cross sectional intercepts and slope parameters is given by (25.3) vs (25.5) which makes the Null claim that the cross-sectional slopes and intercepts are respectively identical across cross-sections. A second alternative hypothesis is one that argues for equal intercepts but different slopes across cross-sections. On the basis of the relevant SSR values in Table XIII we see that the calculated F is equal to .7 which is less than the critical F of 1.50. We therefore cannot reject the Null hypothesis that a pooled OLS model is the optimal choice of model specification in this instance.

The final test in this connection regards the Null claim contained in (25.3) vs (25.6) that the cross-sectional slopes and intercepts are best modeled in a single OLS regression as opposed to a pooled model which allows both cross-sectional slopes and intercepts to be free across cross-sections. As in the previous case, we estimated two separate regressions-- an unrestricted pooled regression without any restrictions on the slopes or intercepts of the individual cross-section and a restricted model with the slope and intercept coefficients constrained to be equal across cross-sections. As displayed in Table XIII, the F value calculated with the appropriate SSR values is equal to 1.96. Given that at the 5 % level of significance the $F_{27,96}$ Statistic is approximately 1.62 we are unable to reject the Null hypothesis that the 321 Crack

relation is best modelled by a set of individual cross-sectional autoregressions as opposed to being modeled as a pooled OLS regression with identical cross-sectional intercepts and identical slope coefficients.

The results of our F -tests for joint significance of the parameters of the nested 321 crack model indicates that formulation (25.6)--taken to mean separate autoregressions of the 321 crack-- yields the "best" parameterization of this model. But, given that this parameterization permits a dual specification viz., individual autoregressions or a Seemingly Unrelated Regression (SUR) approach we utilize the F test to determine which approach is "optimal". As before, we identify the maintained hypothesis, which, in this case is that the SUR model represents the "correct" formulation of the 321 crack as opposed to a specification based on estimating separate autoregressions. The results of this investigation are depicted in Table XIV where it is seen that the calculated F value is equal to .6 which, since it is less than the 5 % critical value of 1.43 suggests that we are unable to reject the null claim of the SUR model as the "optimal" parameterization of the 321 crack.

**Table XIII. Summary Results of Joint Significance Tests
for the Parameter Estimates of the 321 crack regressions***

Model	Restr.	SSR _R	SSR _U	F _{calc}	DEGF _N	DEGF _D	F _{crit}	Decis
32.1	32.1vs32.2	4485	1963	40.3	162	157	2.29	Rej.
32.2	32.1vs32.3	4485	969	192.2	162	159	2.68	Rej.
32.3	32.1vs32.4	4485	917	74.9	162	154	1.96	Rej.
32.4	32.2vs32.4	1963	917	58.5	157	154	2.68	Rej.
32.5	32.3vs32.4	969	917	1.8	159	154	2.29	Acc.
32.6	32.3vs32.5	969	762	0.7	159	113	1.50	Acc.
	32.3vs32.6	969	625	1.96	123	96	1.50	Acc.

* Notes: 1. Approximate critical values at the 5% level of significance. 2. Key: SSR_R, SSR_U--Sum of Squared Residuals for the restricted and unrestricted models respectively. F_{calc}--the calculated F value. DEGF_N, DEGF_D -- degrees of freedom in the numerator and the denominator respectively.

**Table XIV. Model Selection F-Test Results:
SUR vs. Individual Regressions.**

Restric.	SSR_u	SSR_0	F_{calc}	$DEGF_u$	$DEGF_0$	F_{crit}	Decis.
$H_0: \epsilon_{it}$ are Correlated requiring GLS Estimation.	1033	800	0.6	186	125	1.43	Accept

Note: See Table XV for key to column headings.

6.4 Summary and Conclusions

Starting out with our nested model and performing all of the implied joint tests of significance we arrive at the conclusion that any model that seeks to explain the variation of the individual cross sections of the 321 crack spread must be parameterized by variables capturing both regressor and fixed effects. Moreover, given the existence of contemporaneous correlation among the cross sectional crack spreads, it was established that such a parametrization becomes optimal only in the context of a SUR estimation process.

6.5 SUR Estimation of the 321 Crack

Model Description

The estimation of our Zellner SUR model of the 321 crack proceeds in the following manner. First, we form the following system of regressions,

$$\text{Janret}^i_t = \beta_0 + \beta_1 \text{Janret}^i_{t-1} + \beta_2 \text{Janret}^i_{t-2} + \beta_3 \text{Janret}^i_{t-3} + \mu_t \quad (31)$$

$$\text{Julret}^j_t = \beta_0 + \beta_1 \text{Julret}^j_{t-1} + \beta_2 \text{Julret}^j_{t-2} + \beta_3 \text{Julret}^j_{t-3} + \mu_t$$

where Janret^i_t represents the i th cross-section of the crack rate of return series for all i defined over January 1986, January 1987 and January 1988; and Julret^j_t reflects the j th cross section of the crack rate of return for j equal to July 1986, July 1987, and July 1988. The data were stacked such that January's observations were concatenated with those of July for the i 'th year.

It is convenient to rewrite (31) in the familiar form $Y = X\beta + \epsilon$, where Y and ϵ are T element vectors, β is an k element vector and X is a matrix of dimension $T \times k$. As is traditional, the residuals in the SUR model are assumed to be uncorrelated within a given cross-section but are considered to be

correlated across cross-sections-i.e.,

$$\begin{aligned} \text{cov}(\epsilon_{it}, \epsilon_{js}) &= \sigma_{ij} \quad \forall t=s \\ &= 0 \quad \forall t \neq s \end{aligned} \quad (32)$$

The estimation of (31) proceeds by first estimating each individual regression using OLS. Following the OLS estimation, the respective residuals are recovered and used to compute sample estimates of the population covariances σ_{ij} in the following manner,

$$\sigma_{ij} = \{1/(T-k)\} \sum \epsilon_{it} \epsilon_{jt} \quad (33)$$

where k represents the number of parameters estimates in the regression. Finally, the six cross-section equations are jointly estimated by way of GLS utilizing the above estimates of the population covariances.

Table XV. SUR Estimation Results of the 321 Crack Series.

Cross-Section	Parameter	Estimate	Std_Err	t_ratio
Janret86	β_0	2.14	2.70	0.80
	β_1	0.37	0.19	1.94
	β_2	-0.04	0.19	0.19
	β_3	0.44	0.16	2.69
Janret87	β_0	6.88	3.89	1.77
	β_1	0.33	0.17	1.90
	β_2	0.06	0.20	0.28
	β_3	0.27	0.18	1.47
Janret88	β_0	3.37	3.17	1.06
	β_1	1.17	0.37	3.15
	β_2	-0.90	0.39	2.33
	β_3	0.52	0.46	1.12
Julret86	β_0	3.64	2.60	1.40
	β_1	0.51	0.18	2.81
	β_2	0.24	0.19	1.30
	β_3	0.10	0.15	0.65
Julret87	β_0	-13.68	2.61	5.25
	β_1	0.90	0.20	4.42
	β_2	0.32	0.22	1.45
	β_3	0.46	0.28	1.63
Julret88	β_0	-16.82	9.55	-1.76
	β_1	2.17	0.50	4.32
	β_2	-1.58	0.51	3.12
	β_3	1.45	0.49	2.94

6.6 SUR Results

The empirical results obtained from estimating the SUR system are tabulated in Table XV. In line with our earlier discussion of Samuelson's martingale theorem, the relevant test for the existence of a martingale in the autoregressive representation of the individual 321 crack series is that the $\beta_1=1$ while the other parameter estimates are hypothesized to be individually equal zero.

The results of our estimation of these autoregressions are not directly interpretable since we are investigating the null hypothesis that the 321 crack series for the i 'th month is a martingale and therefore has a unit root. To aid us in the above context, we employed the Dickey-Fuller (DF) unit root test in separate estimations of each 321 crack cross section. As before, the DF test involves estimating equations like the following,

$$\Delta \text{Janret}_{it}^j = \alpha + \beta_1 \text{Janret}_{it-1}^j + \sum \varphi_i \Delta \text{Janret}_{it-i}^j + \epsilon_t \quad (34)$$

$$\Delta \text{Julret}_{jt}^i = \delta + \beta_j \text{Julret}_{jt-1}^i + \sum \gamma_j \Delta \text{Julret}_{jt-k}^i + v_t \quad (35)$$

where $\beta_1 = \beta_j = \rho - 1$, ϵ_t and v_t are mean zero random disturbances and the hypotheses to be tested for the various 321 crack cross sections are that respectively,

$$H_0: \text{Janret}_{it}^j \sim I(1) \quad \text{and,}$$

$$H_a: \text{Janret}_{it}^j \sim I(0)$$

$$H_0: \text{Julret}_{it}^j \sim I(1) \quad \text{and,}$$

$$H_a: \text{Julret}_{it}^j \sim I(0)$$

We exhibit the results of the DF unit root tests of the crack series in Table XVI. If we were to base our tests of parameter significance upon standard distribution theory, it is clear that such tests would have characterized the Janret86 and Janret87 321 crack series as being mean reverting given the relative statistical unimportance of their respective intercepts and first lags. In a word these series appear to be distributed as $I(0)$ --i.e., as white noise-- and hence represent series that appear to be generally predictable. If indeed these series were predictable then it would have been worthwhile for a speculator to have bought both contracts when they were priced below their respective means and to have sold them when their prices rose above their means thereby making an assured profit on the transaction. In contrast, critical values from the correct non-stationary distribution theory of Dickey-Fuller reveal that all of the cross sectional regressions are martingale processes and as such imply that the underlying crack contracts were all weak form efficient with no prospects for the speculative appropriation of unexploited profit opportunities.

Table XVI. Dickey-Fuller Unit Root Tests for The Cross-Sectional NYMEX 321 Crack Series.

Cross-Section	τ_μ -Ratio	Decision
Janret86	-1.28	Accept H_0
Janret87	-1.39	Accept H_0
Janret88	-1.54	Accept H_0
Julret86	4.07	Accept H_0
Julret87	5.18	Accept H_0
Julret88	2.23	Accept H_0

* The Relevant critical value of -3.0 is the (non-augmented) Dickey-Fuller statistic for a 5% level of significance. The rejection region is $(\theta|\theta < -3.0)$.

Chapter 7.

7.1 Cointegration Theory: Implications for Weak Form Tests

Our analysis up to this point has clearly established support for the presence of weak form efficiency characteristics in the futures energy complex both *within* and *among* these markets. Since the previous set of results essentially beg the question as to the nature of the price relationships across these markets particularly the issue of their long run (dis-)equilibrium we shall now introduce a framework based on cointegration theory³⁴ through which we will seek to provide some answers to the above and other relevant issues.

As a first step, we provide a brief background to the econometrics of cointegration. We begin with the definition of the notion of an integrated time series of which the random walk is perhaps the simplest example. Thus given

³⁴Engle Robert, F & Granger C. W. (1987) "Co-integration and Error Correction: Representation, Estimation, and Testing" *Econometrica*, vol. 55, No. 2, pp 251-276.

Hendry, David (1986) "Econometric Modelling With Cointegrated Variables: An Overview" *Oxford Bulletin of Economics and Statistics*, vol. 48, No. 3, pp 201-212. See also the other articles in the same issue of the *Oxford Bulletin*.

$$F_t = F_{t-1} + \epsilon_t \quad , \text{where } \epsilon_t \sim \text{IN}(0, \sigma^2) \quad (36)$$

$$\Rightarrow F_t = \sum_{j=0}^{t-1} \epsilon_{t-j} \quad \text{for } F_0 = 0 \quad (37)$$

which implies that the current value of F is conditioned on the sum of all past innovations ϵ_t . From (36) we observe that taking the first difference of F_t will render the series stationary. The notion of integration in the context of non-stationary time series concerns the degree of differencing required to make a given series stable in its first two moments. If a given series is $I(1)$ --i.e., integrated of order one --then this series will exhibit no tendency to return to its mean or trend value. Series that are $I(0)$ however, do show a tendency to return to their central values following any dislocation by random disturbances.

Cointegrated series are series that jointly exhibit stable and consistent long run dynamical behavior. Thus, given the following two series F_t and S_t each being distributed as $I(1)$ then we can define their cointegration in the following manner,

$$z_t = F_t - \phi S_t \quad , \text{ where } z_t \sim I(0) \quad (38)$$

The relationship in (38) essentially implies that although each series is $I(1)$ there exists a linear combination of them acting through the cointegrating vector Φ that forces the individual series into long run equilibrium thus making the innovation z_t $I(0)$ --i.e., white noise. A fundamental implication of the above as demonstrated by Granger(1986)³⁵ is the fact that to the extent that two variables are cointegrated then they both possess an underlying "Error Correction Model" (ECM) formulation that is representable as a bivariate vector autoregression of their respective first differences. Algebraically, such a system can be expressed as follows,

$$\Delta F_t = -\pi_1 z_{t-1} + \sum_{i=1}^k \beta_i \Delta F_{t-i} + \sum_{i=1}^m \lambda_i \Delta S_{t-i} + \gamma(B) \xi_{1t} \quad (39)$$

$$\Delta S_t = -\pi_2 z_{t-1} + \sum_{j=1}^k \mu_j \Delta F_{t-j} + \sum_{j=1}^m \lambda_j \Delta S_{t-j} + \gamma(B) \xi_{2t} \quad (40)$$

where (B) is a finite polynomial in the backshift operator B and ξ_{1t} and ξ_{2t} are jointly distributed Gaussian error processes. Parameterizing a model with cointegrated variables in the ECM form permits two vital advantages. First, given that the variables in the underlying model to be estimated are all distributed as $I(0)$ then this facilitates the direct

³⁵Granger, C.W.J. (1986) "Developments In The Study Of Cointegrated Economic Variables" Oxford Bulletin of Economics and Statistics Vol. 48, No. 3, pp 216.

application of standard asymptotic theory to tests of hypotheses about model parameters. Second, such a specification, given the existence of lagged changes of one variable in a regression explaining another, leads to a direct test of weak form market efficiency, since, according to the precepts of this theory speculative prices should reflect all currently available information and so including past realizations of an additional regressor series in a dataset containing lagged values of the variable to be explained should not result in any significant increase in the model's forecasting efficiency. In addition to the above, the notion of cointegration also provides an immediate and perhaps more direct test of the claims of weak form market efficiency since, from (26) it follows that to the extent that commodity markets are *jointly efficient* then a linear combination of price pairs *should not* be $I(0)$ (i.e., cointegrated) since this would imply the existence of Granger Causality³⁶ and hence the forecastability of one series using the other.

To carry out our cointegration tests we begin by first establishing the level of integration of each price series in each market. From our earlier (Table IX) results we note that all of our price series were established as being distributed

³⁶In this connection see Granger, C. W. (1969) "Investigating Causal Relations by Econometric Models and Cross-Spectral Methods", *Econometrica*, vol. 37, pp 424-438.

as $I(1)$. Bearing in mind that the 321 crack represents a linear combination of the underlying price series for crude oil, heating oil and unleaded gasoline, we therefore formulate and estimate two sets of cointegration regressions with the price of crude oil as the left hand side variable which is to be "reconciled" or equilibrated with a linear combination of the refined product prices as cointegrands. The advantage of such a formulation is that it allows us to estimate regressions which are linear transformation of the 321 crack and are therefore different from the latter only on the basis of scale. It should be noted that technically we are not required to estimate regressions for all three price pairs given the existence of a transitivity relation under conditions of cointegration³⁷. However, we estimated the following cointegration regressions,

$$PCR_{t,j}^i = \alpha_0 + \beta_1 PUG_{t,j}^i + \beta_2 PHO_{t,j}^i + \epsilon_t \quad (41)$$

where PCR, PHO and PUG represent respectively, the prices of crude, heating oil and unleaded gas respectively, and i indexes the years 1986 to 1988 while j indexes the months January and July.

³⁷In this regard, see Taylor, Mark and Tonks, I (1989) "The Internationalization of Stock Markets and the Abolition of U.K. Exchange Control", The Review of Economics and Statistics vol. 61, No. 2, p 334.

**Table XVII. Cointegrating Regressions and Augmented
Dickey-Fuller Tests for a Unit Root in the
Cointegrating Residuals^a**

Contract	Commodity-Pair	α	β_1	β_2	R^2	DF ³⁸
JAN86	CR-(UG,HO)	-0.44	0.57	0.36	0.99	2.72
JAN87	CR-(UG,HO)	-0.07	0.52	0.47	0.93	3.10
JAN88	CR-(UG,HO)	-0.08	0.51	0.51	0.90	2.10
JUL86	CR-(UG,HO)	-0.04	0.11	0.78	0.96	3.83
JUL87	CR-(UG,HO)	-0.10	0.00	1.10	0.90	1.10
JUL88	CR-(UG,HO)	0.12	0.23	0.36	0.34	2.30

a: Reported coefficient estimates are OLS model based. Standard errors are not relevant in this context and are not reported (Granger & Newbold, 1977, pp. 202-214)³⁹. R^2 is the coefficient of determination. DF is the Dickey-Fuller statistic for the maintained hypothesis of non-cointegration. The approximate critical values for the DF Statistic at the 5% and 10 % levels of significance are respectively, -3 and -2.63 with the rejection region being defined for algebraically smaller values than -3 or -2.63.

³⁸See Said, S. E. and Dickey, D. A. (1984): "Testing for Unit Roots in Autoregressive-Moving Average Models of Unknown Order", *Biometrika*, Vol. 71, pp. 599-607.

³⁹Granger, C. W. and Newbold, P. (1977) *Forecasting Economic Time Series* New York: Academic Press, pp. 202-214.

Table XVII contains the results of estimating the cointegrating regressions and of testing for covariance stationarity or unit roots in the cointegrating residuals. The null hypothesis of noncointegration is rejected at the 5 % level of significance for both the January 1987 and July 1986 price series and at the 10 % level of significance for the January 1986 price series. Thus of the six sets of price relationships investigated for the existence of cointegrated processes, three such series (January 1986, January 1987 and July 1986) appeared to be thus characterized. Bearing in mind our earlier discussion about the ECM formulation, the fact that the January 1986, January 1987 and July 1986 individual price relationships are characterized by price pairs that are cointegrated implies that the lagged price series from the heating oil and unleaded gas markets should aid in forecasting changes in the level of crude prices. But if such regressor effects are indeed possible then it becomes clear that these markets are *jointly weak form inefficient* and there were opportunities to further speculate away the profits contained in the intermarket price differentials.

Our cointegration results have established the existence of joint weak form inefficiency in at least half of the individual markets constituting the energy complex. As we have seen, such cointegration results also imply that for the three instances of cointegration, the cointegrated price series are

representable in terms of an "Error Correction Formulation" - i.e., as a bivariate vector autoregressive representation in the first differences of both the cointegrating variables as well as the lagged levels of the cointegrating residuals⁴⁰. The implication of this Error Correction formulation in which the integrated levels of the cointegrated pair of variables appear in the same equation is that it becomes possible not only for one variable from the cointegrated pair to be used in forecasting the other (thus confirming the joint inefficiency result) but also direct tests of exogeneity and the direction of causality can be made. Thus, given cointegration of particular markets, we are in a position to explore whether, for instance, Granger_causality⁴¹ flows from one primary market to the others (e.,g. does the crude market Granger cause the heating oil or the unleaded gas markets?) or whether there is an interdependence or bi-directional feedback mechanism in place.

In pursuit of the issue of Granger causality in the

⁴⁰In this regard, see Granger, C. W. (1986) "Developments in the study of Cointegrated Economic Variables" Oxford Bulletin of Economics and Statistics, vol. 48, No. 3, pp. 201-228.

⁴¹Granger's definition of causality between two variables in a given system is as follows. Given a system consisting of two variables x and y at time t . If the errors in forecasting y can be reduced by including the historical values of x in the forecasting model then x can be said to cause y . See, Granger, C. W. (1969) *ibid.* pp 424-438.

energy futures markets, we estimated the following augmented unrestricted vector autoregressions for crude oil on heating oil and unleaded gasoline. Similar analyses checking for reverse Granger causality were estimated for unleaded gasoline on crude oil and heating oil and for heating oil on unleaded gasoline and crude oil.

$$\begin{aligned} \Delta CR_t = & \beta_0 + \beta_1 HO_{t-1} + \beta_2 CR_{t-1} + \beta_3 \Delta HO_{t-1} + \beta_4 \Delta HO_{t-2} + \beta_5 \Delta CR_{t-1} + \beta_6 \Delta CR_{t-2} \\ & + \beta_7 UG_{t-1} + \beta_8 \Delta UG_{t-1} + \beta_9 \Delta UG_{t-2} + \epsilon_{1t} \end{aligned} \quad (42)$$

Bearing in mind that ΔHO , ΔUG and ΔCR represent the first difference of the heating oil, unleaded gasoline and crude oil series respectively, our Granger causality test involves establishing the degree of joint statistical significance of the lagged UG and ΔUG and the lagged HO and ΔHO in equation (42). We exhibit our Granger causality results in Tables XVIII, XIX and XX where we see that applying an incremental F test in most cases (i.e., 24 out of 36) the maintained hypothesis of exogeneity was upheld at the 5 % level of significance implying that for these contracts in question, there were no specific inter market source of origination of influence. Of the thirty six contracts, at least twelve could not be rejected at the 5 % level as having "originating" or "feedback" influence on other contracts in other markets. Also, of these twelve price pairs with causality properties, all but two (January 1988 CR on UG and January 1988 UG and

HO) were characterized by "feedback" effects thus indicating the fundamental uni-directional nature of the effects.

Given the existence of cointegrated price series we would expect observing some evidence of Granger causality in at least one of the two product price series in the ECM regression for each of the following contract years, January 1986, January 1987 and July 1986. Since, out of the three contract years in question we observe some evidence of Granger causality in two of these years (January 1986 HO on CR and July 1986 UG on HO and CR on UG) the above exogeneity results appear to be fairly consistent with our cointegration results and the ECM implication for our cointegrated price series.

Table XVIII. Augmented Unrestricted Vector Autoregression based Exogeneity Tests in the Crude Oil Futures Market.

NULL HYPOTHESIS: ^a				
Contract	HO Does not Granger Cause CR		UG Does not Granger Cause CR	
	F_{Calc}	$F_{(D,N)}$	F_{Calc}	$F_{(D,N)}$
JAN86	3.84	3.41	4.82	3.41
JAN87	2.10	3.03	0.40	3.03
JAN88	8.03	2.99	7.30	2.99
JUL86	0.67	3.16	0.91	3.16
JUL87	0.85	3.49	2.17	3.49
JUL88	11.14	3.14	0.80	3.14

a: F_{Calc} represents the calculated F value for the joint significance of lagged HO and UG variables in the CR Regression.

**Table XIX. Augmented Unrestricted Vector Autoregression
based Exogeneity Tests in the Heating Oil Futures Market.**

NULL HYPOTHESIS: ^a				
Contract	UG Does not Granger Cause HO		CR Does not Granger Cause HO	
	F _{Calc}	F _(0,N)	F _{Calc}	F _(0,N)
JAN86	2.33	3.41	0.33	3.41
JAN87	0.56	3.03	1.53	3.03
JAN88	4.17	2.99	2.83	2.99
JUL86	5.00	3.16	124.00	3.16
JUL87	2.13	3.49	1.33	3.49
JUL88	0.26	3.41	0.40	3.41

a: F_{Calc} represents the calculated F value for the joint significance of lagged UG and CR in the HO regression.

Table XX. Augmented Unrestricted Vector Autoregression based Exogeneity Tests in the Unleaded Gasoline Futures Market.

NULL HYPOTHESIS: ^a				
Contract	HO Does not Granger Cause UG		CR Does not Granger Cause UG	
	F_{Calc}	$F_{(0,N)}$	F_{Calc}	$F_{(0,N)}$
JAN86	3.29	3.41	0.87	3.41
JAN87	0.85	3.03	0.85	3.03
JAN88	9.10	2.99	6.78	2.99
JUL86	0.63	3.16	57.20	3.16
JUL87	1.60	3.49	4.00	3.49
JUL88	0.42	3.41	0.28	3.41

a: F_{Calc} represents the calculated F value for the joint significance of lagged HO and CR in the UG regression.

7.2 Summary and Conclusions

There are two primary conclusions to be drawn from our exogeneity analysis of the price relationships across the individual energy markets. First, exogeneity analysis is a relatively simple but useful method of actually identifying, for particular cointegration relationships, the actual source as well as direction of causality. Uncovering such information allows us to specifically identify the precise price pair for which there was untapped speculative profit opportunities. Second, since our exogeneity results point out that 24 out of 36 price pairs reveal no evidence of unexploited speculative profits, then in general, and consistent with our earlier cross-sectional, time series and cointegration results, they would seem to supply additional confirmation that these markets were weak form efficient. However, it is of vital importance to note that the above notwithstanding, and in the context of nonstationary behavior in the underlying crack series our application of the more sophisticated nonstationary econometric techniques based on Dickey_Fuller and Cointegration Theory has enabled us to uncover fairly significant evidence of weak form inefficiency in three out of six instances. That this is a fundamentally non-trivial result is seen even more clearly when one takes into account the fact that our construction of the cointegration models was based

upon an incomplete specification of the energy complex due to our inability to obtain relevant data for the No. 6 Residual Oil and Propane series. Failure to include the complete cointegrating vector in the estimation of a cointegrated system may result in parameter bias in part caused by a failure to whiten the error process. When this occurs there is often a propensity toward accepting the null of non-cointegration among the incomplete set of cointegrated variables.⁴² Also, given that the results of our ECM modelling in contrast to those for our cointegration analysis revealed evidence of causality in one third of the cases checked when cointegration analysis would only anticipate such causality in at most one-sixth of such instances, in part would seem to confirm this tendency to accept the Null of non-cointegration (i.e., weak form efficiency) as a consequence of our failure to specify and estimate a complete cointegrating vector.

⁴²In this regard see, Hall, S.G. (1986): "An Application of the Granger & Engle Two-Step Estimation Procedure to United Kingdom Aggregate Wage Data", Oxford Bulletin of Economics and Statistics, Vol. 48, No. 3, pp. 229-239.

Chapter 8.

8.1 Grand Summary and Conclusions

The primary mission of this study was the investigation of the weak form efficiency properties of NYMEX's 321 crack spread which we established is calculated by subtracting the revenues (cost) derived from the sale (purchase) of 2 unleaded gasoline plus 1 No. 2 heating oil contracts from the cost (revenue) of (from) 3 crude oil contracts.

We began our analysis with a brief survey of the general theoretical efforts around empirically validating the concept of weak form efficiency in a wide variety of asset markets. Following this, we introduced the specific contracts traded at NYMEX and gave a detailed description of their specific attributes while showing how the fact that such contracts were indeed tradeable conferred a number of benefits upon the participants in these markets.

Our next concern was to establish the fact that the 321 crack spread although a rule of thumb did possess some microeconomic foundations albeit as a special case of an optimizing process of a representative risk averse refiner. In establishing this fact, we were able to show the complex interaction of production and hedging decisions and how these

were reconciled in the context of a risky environment and a binding resource constraint.

After performing some summary statistical calculations to provide a description of the underlying statistical character of the individual price as well as crack series, we estimated a set of AR(3) regressions which combined with the special econometrics of Dickey-Fuller enabled us to conclude that the stochastic behavior of each individual cross section was consistent with the notion of weak form efficiency. As a refinement to the above, we turned our focus to the price interactions across markets, arguing that these relationships were of more immediate importance to market participants as opposed to the behavior of singular price series. In so doing, we applied a Zellner like estimation technique to control for contemporaneous correlation of the cross sectional disturbances and concluded after the assaying the results of a series of tests of joint parameter significance that the cross sections all gave evidence of martingale like behavior and hence of weak form efficiency.

In pursuit of a deeper analysis of the inter-market price relationships, we decided to introduce the relatively new econometric technique of cointegration theory to probe more deeply into the equilibrium and causality relationships existing among the cross sectional crack series. In this

regard, we formulated and estimated several cointegration models of the crack and concluded that there was indeed evidence of cointegration (and hence weak form market inefficiency) among three out of six of the cross sections. This is an important result particularly when one considers the fact that were we to have at our disposal the full complement of refined products in the energy complex we would have been in a position to better uncover the cointegrated and exploitable relationships that appear to underlie these cross sections.

Bibliography

Abken, P. (1989): "An Analysis of Intramarket Spreads in Heating Oil Futures" Journal of Futures Markets, Vol., 9 No. 1, pp. 77-86.

Anderson, R. W., and Danthine, Jean-Pierre (1983): "Hedger Diversity in Futures Markets" The Economic Journal, Vol. 93, pp. 375.

Balestra, P. and Nerlove M, (1966): "Pooling Cross-Section and Time Series Data in the Estimation of a Dynamic Model: The Demand for Natural Gas," Econometrica, Vol. 34, No. 4, pp. 585-612.

Bird, W. (1987): "Continuity and Reversal in Oil Spot Price Movements" Energy Economics, (April), pp. 73-81.

Bohi, D. and Toman, M. (1987): "Futures Trading and Oil Market Conditions" Journal of Futures Markets, Vol. 7, No., 2 pp. 203-221.

Cargill, F. and Rausser, G. (1972): "Time and Frequency Domain Representations of Futures Prices as a Stochastic Process" Journal of the American Statistical Association, Vol. 67, No. 337 pp. 23-30.

Case, K. E. and Shiller, R. J. (1989): "The Efficiency of the Market for Single-Family Homes", *American Economic Review*, Vol. 79, No. 1 pp. 125-137.

Cicchetti, P, Dale, C and Vignola, A. (1979): "Usefulness of Treasury Bill Futures as Hedging Instruments," *Journal of Futures Markets* Vol., 1 No. 3, pp. 379-387.

Cootner, P. (1967): *The Random Character of Stock Market Prices*, Cambridge, MIT Press: pp. 100-128.

Dickey, D. A. and Fuller, W. A. (1979): "Distribution of the estimators for autoregressive time series with a unit root" *Journal of the American Statistical Association*, Vol., 74, pp. 427-431.

----- (1981): "Likelihood Ratio Statistics for Autoregressive Time Series with a Unit Root" *Econometrica* Vol., 49, pp. 1057-1072.

Engle, R and Granger. C. W. (1987): "Cointegration and Error Correction: Representation, Estimation, and Testing" *Econometrica*, Vol., 55, No. 2 pp. 251-276.

Fama, Eugene F. (1970): "Efficient Capital Markets: A Review of Theory and Empirical Work," *Journal of Finance*, Vol., 25 No. 2 pp. 383-417.

Fuller, W. A. (1976): *Introduction to Statistical Time Series*. New York: John Wiley & Sons.

Gibbons, M. R. and Hess, P. (1988): "Day of the Week Effects and Asset Returns," *Journal of Business*, Vol., 54, No. 4 pp. 579-596.

Gjolberg, O. (1985): "Is the Spot Market for Oil Products Efficient?," *Energy Economics*, (October) pp. 231-236.

Granger, C. W. (1969): "Investigating Causal Relations by Econometric Models and Cross-Spectral Methods," *Econometrica*, Vol. 37, pp. 424-438.

----- (1986): "Developments In The Study Of Cointegrated Economic Variables" *Oxford Bulletin of Economics and Statistics*, Vol. 48, No. 3, pp. 216.

-----and Newbold, P. (1977): *Forecasting Economic Time Series*. New York: Academic Press.

Hall, S. G. (1986): "An Application of the Granger & Engle Two-Step Estimation Procedure to United Kingdom Aggregate Wage Data" Oxford Bulletin of Economics and Statistics, Vol. 48, No. 3, pp. 229-239.

Hasza, D. P. and Fuller, W. A. (1979): "Estimating for Autoregressive Processes with Unit Roots" Annals of Statistics, Vol. 7, pp. 1106-1120.

Hendry, David (1986): "Econometric Modelling with Cointegrated Variables: An Overview" Oxford Bulletin of Economics and Statistics, Vol., 48, No. 3, pp. 201-212.

Leroy, S. (1973): "Risk Aversion and the Martingale Property of Stock Prices," International Economic Review, Vol. 34, No.4, pp. 436-446.

Maddala, G. S. (1969): "The Use of Variance Components Models in Pooling Cross Section and Time Series Data," Econometrica, Vol. 39, No. 2, pp. 341-358.

----- and Nerlove, M. (1971): "Further Evidence on the Estimation of Dynamic Economic Relations from a Time Series of Cross Sections," Econometrica, Vol. 39, No. 2, pp. 359-381.

Mandelbrot, B. (1966): "Forecasts of Future Prices, Unbiased Markets, and Martingale Models" Journal of Business, Vol. 39 No. 1 pp. 242-255.

Moriarity, M. (1975): "Cross Sectional, Time Series Issues in the Analysis of Marketing Decision Variables", Journal of Marketing Research, Vol. 12, pp. 142-50.

Osborne, M. (1966): "Brownian Motion in the Stock Market" Operation Research, Vol. 7, No. 2.

Praetz, P. (1975): " Testing the Efficient Market Theory on the Sydney Wool Futures Exchange" Australian Economic Papers, Vol. 14.

Puglisi, D. J. (1978) " Is the Futures Market for Treasury Bills Efficient?" The Journal of Portfolio Management, pp. 64-67.

Rendelman, R. and Carabini, C. (1979): " The Efficiency of the Treasury Bill Futures Market," Journal of Finance, Vol. 34, No. 4, pp. 895-914.

Roll, R. (1970): The Behavior of Interest Rates, New York: Basic Books.

Samuelson, P. (1965): "Proof That Properly Anticipated Prices Fluctuate Randomly" *Industrial Management Review*, Vol. No. 2, pp. 41-49.

Taylor, M. and Tonks, I. (1989): "The Internationalization of Stock Markets and the Abolition of U.K. Exchange Control," *The Review of Economics and Statistics*, Vol. 61, No. 2, pp. 334.

Said, S. E. and Dickey, D. A. (1984): "Testing for Unit Roots in the Autoregressive-Moving Average Models of Unknown Order," *Biometrika*, Vol. 71, pp.599-607.

Zellner, A. (1962): "An Efficient Method of Estimating Seemingly Unrelated Regressions and Tests for Aggregation Bias" *Journal of the American Statistical Association*, Vol. 57, pp. 348-368.