

A STATE SPACE FORECASTING APPROACH

TO

COMMODITY FUTURES TRADING

by

Richard Carel Marshall

**A Dissertation Submitted to the Faculty of the
DEPARTMENT OF MINING AND GEOLOGICAL ENGINEERING**

**In Partial Fulfillment of the Requirements
For the Degree of**

**DOCTOR OF PHILOSOPHY
WITH A MAJOR IN MINERAL ECONOMICS**

**In the Graduate College
THE UNIVERSITY OF ARIZONA**

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**A state space forecasting approach to commodity futures
trading**

Marshall, Richard Carel, Ph.D.

The University of Arizona, 1991

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and recommend that it be accepted as fulfilling the dissertation requirement
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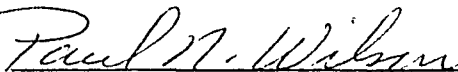
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ACKNOWLEDGMENTS

I would like to express my sincere appreciation to Dr. DeVerle Harris, my dissertation director, who provided the inspiration for this research by introducing me to the state space forecasting method. His support and guidance during my graduate studies at the University of Arizona are gratefully acknowledged. I would also like to thank Dr. Michael Rieber, Dr. Richard Newcomb, and Dr. Paul Wilson for their advice and encouragement over this period.

The following individuals collected or provided data used in this research: my niece, Emily King; Greg Newton of the Metal Bulletin; Dorothy Harris of the U.S. Bureau of Mines; and Warren Clements of Piper Jaffray & Hopwood Incorporated. Their assistance is greatly appreciated.

I wish to express my gratitude to the U.S. Forest Service, and especially to Gary Morrison, for making it possible for me to return to school. Betty Dee Russ, also of the U.S. Forest Service, deserves recognition for her helpful comments and suggestions on early drafts.

This endeavor required significant sacrifices on the part of my wife Ellen and my children Ann, Ian, and Colin. I will be eternally grateful to them for their patience and understanding.

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ABSTRACT

State space forecasting originated in the mid-1970's from engineering models based upon the Kalman filter. To date, the application of state space forecasting to commodity and financial markets has been limited. This study examines a system for trading futures contracts using state space forecasts of commodity futures prices. The system is evaluated for a speculative asset (gold) and a nonspeculative commodity (copper). Price forecasts are developed from multivariate state space models, and the variables considered in the models are those which, according to economic theory, may influence price movements. It is demonstrated that the relative importance of the different economic variables changes over time.

Through simulated trading of copper and gold futures contracts, it is also shown that significant profits can be generated from the state space forecasting approach, especially when prices are trending upward or downward fairly continuously. Relaxing the position limit of one contract substantially increases profits. The results suggest that the copper and gold futures markets may be inefficient in the semistrong sense.

CHAPTER ONE

INTRODUCTION

1.1 Commodity Futures Trading Systems

A number of different trading strategies and systems are available to potential participants in futures markets. Some of these have been popular for many years, while others have emerged more recently in response to the expansion in the volume of futures trading and the greater accessibility of computers. Although such strategies and systems cover a variety of philosophies, they can generally be classified into two broad approaches: fundamental analysis and technical analysis.

1.1.1 Fundamental Analysis

Fundamental analysis focuses on the forces of supply and demand as the determinants of price movements (Barnes, 1979). Factors believed to influence supply and demand are evaluated in order to forecast the future direction of prices. For example, a trader in platinum futures contracts who is an advocate of fundamental analysis may forecast an increase in prices based upon Japan instituting more stringent auto emission standards. Since an important use of platinum is in automobile catalytic converters, the trader would view the new regulations as having a positive effect on platinum demand and, hence, on prices.

The fundamental analysis methods used to forecast prices range from relatively unsophisticated, casual empiricism, such as a judgment that prices of a particular commodity will fall due to the increase in supply over that of last year, to complex, multiequation econometric models. Positions are established based upon whether current prices are well below the forecast or well above. The appropriate position is then held until the predicted price has been met. Fundamental analysis may consider supply and demand statistics over periods of up to several years, and substantial profits can be generated from sound, long-range fundamental analysis, even just by knowing the direction of price changes.

1.1.2 Technical Analysis

In contrast to fundamental analysis, technical analysis essentially ignores the causes of price movements and concentrates instead only on "market action" as portrayed by information on prices, volume, and open interest. The primary foundation of technical analysis, according to Murphy (1986, p. 2), is that "market action discounts everything." Technicians believe that all factors (economic, psychological, etc.) are reflected in the market price and that prices tend to move ahead of the known fundamentals. Thus, by studying only prices and supporting technical indicators, such as volume and open interest, technicians can determine the future direction of the market.

Technical analysis is also based upon the premises that "prices move in trends" and "history repeats itself" (ibid.). The trend component of a price series is critically important to the technical analysis of futures markets, particularly to those who use the trend-following subset of technical analysis methods. Their objectives are to identify trends as they develop and to trade in the direction of the trends.

Completing the foundation of technical analysis is the notion that history repeats itself. Thus, a knowledge of what has happened in the past is essential to understanding the future. Although the distinctions are not always clear-cut, trading systems based upon technical analysis of futures markets can be classified into the categories of trend following, character-of-market, charting, and price forecasting.

1.1.2.1 Trend Following

Trading systems based upon trend following are designed for markets where prices are moving upward or downward in some identifiable pattern (Taylor, 1986). Trend-following systems typically are far less effective (and, hence, less profitable) when prices are relatively constant over time.

The most popular trend-following system is the moving average (MA)

$$(1) \quad MA_t = \frac{P_t + P_{t-1} + \dots + P_{t-(n-1)}}{n}$$

where: P_t = the price at time, t

n = number of days used in the calculation

The idea behind this system is that the moving average line of prices represents the current growth line of the trend, and if actual prices diverge from this growth trend, the current trend is suspect and a change in actual prices to a new, oppositely directed trend has occurred. The system is applied by comparing today's price to today's MA. If the price crosses the MA from below, this generates a *buy* signal. If the price crosses the MA from above, this is a *sell* signal. Sometimes, rather than comparing today's price with the MA, a moving average of shorter length is compared with one of longer length (e.g., 10-day MA versus 40-day MA). Other trend-following systems include the major price trend directional indicator (MPTDI) and the commodity channel index (CCI). Least squares regression is also occasionally mentioned as a trend-following technique.

1.1.2.2 Character-of-Market

Character-of-market trading systems, sometimes referred to as nontrend-following systems, are most effective in situations where prices are fluctuating within a horizontal band or trading range. They can, however, also be useful during trending phases by signalling the market extremes of overbought or oversold conditions. The Contrary Opinion approach and the various oscillators are examples of

character-of-market systems.

Oscillators measure momentum or the rate of change in prices. Oscillators are plotted at the bottom of a daily price chart, and they are often constructed in a manner such that the midpoint of oscillator band is zero. The basic concept of the oscillator is that if the extreme value of the upper or lower end of the band is reached, prices may have moved too far too quickly and, therefore, are due for a correction. The general rule is to buy when the oscillator is near the lower end of the band (i.e., oversold conditions) and to sell when the oscillator is close to the upper extreme of the band (i.e., overbought conditions). The actual signal of when to buy or sell, however, is often based on the crossing of the zero line. Besides the momentum oscillator, other oscillators include moving average differences, rate of change, J. Welles Wilder, Jr.'s *Relative Strength Index*, George Lane's *Stochastics*, and Larry Williams' %R.

Like oscillators, the Contrary Opinion approach to trading attempts to identify market extremes, but Contrary Opinion is not calculated from price data. Instead, market letters published by commodity professionals are analyzed to gauge the degree of bullish or bearish sentiment. An index representing the percent bullishness is calculated, and the market is considered overbought if the index is, say, above 80; and the market is viewed as oversold if the index, for

example, is below 30. Contrary Opinion is often used in conjunction with other technical analysis tools. (See Murphy (1986) for a discussion of the various nontrend-following trading systems, as well as the charting techniques presented below.)

1.1.2.3 Charting

Many traders, known as chartists, use the patterns or formations which appear on price charts as a basis for trading futures contracts. Among the more popular techniques which fall into this category are pattern identification, the Elliott Wave Theory, and point and figure charting.

With pattern identification, the trading strategy is to first recognize the price pattern which is developing and then establish a price objective based on the height of the pattern. Price patterns can be described, in broad terms, as either reversal or continuation patterns.

Reversal patterns mean that a change in the direction of the trend is occurring. Prices move in a zigzag pattern, and the trend is the overall direction of the peaks and troughs. Peaks constitute areas of resistance where selling pressure overcomes the buying pressure and the price increase is reversed, while troughs are support levels where the buying pressure overshadows the selling pressure. Trends are often separated into near-term (less than 2-3 weeks), intermediate (3 weeks-3 months), and major (6 months or more).

Some of the more well-known reversal patterns include the head and shoulders, double or triple tops and bottoms, and spike tops and bottoms. The volume of trading is used to confirm the pattern, and a true breakout point in the price pattern should be accompanied by greater volume. Continuation patterns occur when prices are moving sideways, signalling a pause, which will be followed by a move in the same direction as the preceding formation. Triangles, flags, pennants, wedges, and rectangles are some of the continuation patterns.

In addition to the reversal and continuation patterns, another pattern identification system gaining in popularity in the United States is Japanese candlestick charting (Nison, 1989). Daily high, low, open, and close prices are used to plot the candlestick lines with the thicker part of the candlestick determined by the range between opening and closing prices and thin lines above and below the "real body" of the candlestick representing high and low prices. Some of the candlestick formations include long black or white lines, spinning tops, doji lines, the dark cloud cover, and the three river evening star.

Another charting technique is the Elliott Wave Theory which attempts to provide a basis for understanding why and where price patterns develop. The Elliott Wave Theory was originally applied to stock market averages, and the basic

principle is that prices move in a repetitive pattern of a five-wave advance followed by a three-wave decline. The five waves of the advance consist of three rising or impulse waves (Waves 1, 3, and 5) and two corrective waves (Waves 2 and 4) which move against the upward trend. Comprising the three-wave decline are two decreasing waves separated by one corrective wave against the downward trend. The complete cycle of eight waves applies to different trend lengths ranging from the subminuette which, at a few hours, is the shortest of Elliott's nine trend magnitudes, to the Grand Supercycle of 200 years.

Point and figure charts are often used for intraday trading, and they differ from bar charts in that the dimension of time is essentially ignored. Entries are made on point and figure charts only when price changes of some minimum magnitude occur. Chart paper with, say, ten boxes per inch is used, and a point and figure chart contains alternating columns of X's and O's. The X's signify rising prices while the O's represent declining prices.

The size of the boxes on point and figure charts vary by the commodity, as well as by the objectives of the trader doing the charting. For example, each box in a point and figure chart for gold may represent a price change of \$1.00, but if a less sensitive chart were desired, a box might equal a \$2.00 variation in price. The other factor that can vary

on point and figure charts is the reversal criterion; that is, the number of boxes the market must retrace before starting the next column. The reversal criterion for intraday trading may be one box, but a five-box reversal criterion could be used for analyzing markets over a longer term.

A trading strategy based on point and figure charting relates to the concept of congestion areas, periods of horizontal price movements on the chart. Congestion areas can be an indication of the direction of a future price breakout, and the signal would be considered bearish if the congestion area, defined as the horizontal line on the chart with the greatest number of X's and O's, was near the top of the trading range. A bullish indicator, on the other hand, would exist if the congestion area were close to the bottom of the trading range.

1.1.2.4 Price Forecasting

Judging from the literature, price forecasting techniques are used far less frequently in commodity futures trading than trend-following, character-of-market, or charting methods. The objective of price forecasting is to tell the trader when the current situation represents a bargain, because present prices are considerably different from the forecast. Although forecasts of prices can be developed using the previously discussed fundamental

approach, the so-called mechanical approach is more popular with traders.

Price forecasting techniques used in commodity futures trading include sinusoidal curve fitting, exponential smoothing, Box-Jenkins modelling, and regression analysis (with time as the only independent variable). Some of the price forecasting methods have close counterparts in the trend-following category, differing slightly in the structure of the technique or the trading strategy that is applied.

Exponential smoothing is a class of forecasting methods for which the weights assigned to observations decrease exponentially as the observations become older (Makridakis et al, 1983). Single exponential smoothing is of the form:

$$(2) \quad F_{t+1} = \alpha X_t + (1 - \alpha) F_t$$

where: F_{t+1} = forecast for $t+1$

α = smoothing parameter ranging from 0 to 1

X_t = observation at t

F_t = previous forecast

When the smoothing parameter, α , approaches 1, the new forecast includes a large adjustment for the error in the previous forecast. If α is close to 0, however, there is little adjustment.

Autoregressive, Moving-Average, Integrated (ARIMA) models, also described as Box-Jenkins models, have been cited in discussions of technical analysis of futures markets

(Murphy, 1986). The Box-Jenkins approach involves four phases: model identification, model estimation and validation, and model forecasting. The methodology is based upon statistical models of the autocorrelations in the historical time-series data. Mathematically, the Box-Jenkins model can be expressed in the following manner (Hoff, 1983):

$$(3) \quad \Phi(B)\Phi^*(B)D(B)x_t = \theta_0 + \Theta(B)\Theta^*(B)e_t$$

where: $\Phi(B)$ = regular autoregressive operator

$$= (1 - \phi_1 B - \dots - \phi_p B^p)$$

$\Phi^*(B)$ = seasonal autoregressive operator

$$= (1 - \phi_1^* B^s - \dots - \phi_p^* B^{sp})$$

$D(B)$ = differencing operator

$$= (1 - B)^d (1 - B^s)^D$$

$\Theta(B)$ = regular moving average operator

$$= (1 - \theta_1 B - \dots - \theta_q B^q)$$

$\Theta^*(B)$ = seasonal moving average operator

$$= (1 - \theta_1^* B^s - \dots - \theta_q^* B^{sq})$$

and: s = periods per season

x_t = series values

e_t = random error

d = number of regular differences

D = number of seasonal differences

B = backward difference operator (e.g., $B^m x_t = x_{t-m}$)

ϕ_i = regular autoregressive parameter, $i = 1, \dots, p$

ϕ_i^* = seasonal autoregressive parameter, $i = 1, \dots, p$

θ_i = regular moving average parameter, $i = 1, \dots, q$
 θ_i^* = seasonal moving average parameter, $i = 1, \dots, Q$
 θ_0 = trend parameter

1.2 Description of the Problem

Under certain circumstances, many of the previously discussed systems could undoubtedly generate substantial trading profits. In other situations, however, it is likely that a trader would incur large losses from their application. Following are some of the limitations of the more common trading methods.

Fundamental analysis provides a sound basis for understanding the workings of a particular commodity market, but there are problems associated with using fundamental analysis as the sole basis for a trading strategy. One weakness of the fundamental approach is the length of time required before new information becomes available and is confirmed (Barnes, 1979). Prices may already reflect expectations before the trader is able to incorporate the new data into the model. As evidence of this, little change is sometimes observed in the price of a commodity after disclosure of information that would normally be expected to result in a significant price move. Such information had been anticipated and the price had already reacted to the expectations. The trader belatedly relying on the newly published data to establish or adjust a position may,

therefore, sustain considerable losses or pass up substantial profits.

Other criticisms of the fundamental approach include the vagueness of rules for applying the analyses to a trading method and the lack of built-in timing strategy for entry and exit of a position (Barnes, 1979). Also, where the purpose of the fundamental analysis is to predict future commodity prices, it will be necessary to forecast the exogenous variables. This, of course, can be a significant undertaking, especially for complex models.

Trading systems based on technical analysis are also not without their problems. For example, although trend-following methods (e.g., moving averages) enable the trader to capture profits during significant upward or downward price swings, large losses can occur when prices stay within a trading range for a prolonged period of time (Teweles, Harlow, and Stone, 1974). Long positions will be established as prices approach the top of the trading range and short positions will be taken near the bottom, but prices then reverse direction, rendering the trade unprofitable.¹ Trend-following techniques also suffer from the problem of having to choose a level of sensitivity that minimizes whipsaw

¹A trader who has bought a futures contract or owns a cash commodity is *long*, while one who has sold a futures contract or plans to purchase a cash commodity is *short* (CBOT, 1989).

losses, yet does not indicate a new trend so late that most of the profits are missed. Similarly, the type and amount of penetration necessary before a buy or sell signal is generated must be determined.

In contrast to trend-following methods, the oscillator, one of the character-of-market trading strategies, is most effective when prices are moving horizontally in a trading range. Should, however, prices be trending upward or downward for a sustained period, the oscillator approach will result in losses to the trader (Teweles, Harlow, and Stone, 1974). The oscillator will continue to be in either the overbought or oversold category, prompting the trader to take and maintain a position opposite to that of the trend. Another disadvantage of using oscillators is that price volatility can change, which causes the previous overbought/oversold definitions to no longer be applicable.

Contrary Opinion, the other character-of-market trading strategy discussed above, also has a number of disadvantages associated with it. It is difficult to collect information that accurately reflects the prevailing psychology of the market (ibid.). Quantifying the depth of opinion poses problems, and developing criteria for deciding when to close trades is not easy. Finally, the number of trades from the Contrary Opinion approach may be rather small, since relatively complete consensus on the outlook for a market

does not occur all that frequently.

The almost completely subjective nature of the charting techniques is the major drawback to their use (Teweles, Harlow, and Stone, 1974). The likelihood that actual price patterns would often neatly conform to the examples cited in the textbooks would seem to be quite low, so recognizing a particular formation among the many possibilities would be difficult. Where a large number of traders reach the same conclusion about a price pattern, the result can be a self-fulfilling prophecy, at least for a while. Once the pattern-related buying or selling activity ceases, however, prices can quickly return to more sustainable levels, resulting in sizable losses for the chartist.

Price forecasting techniques, especially those which have a statistical foundation, would appear to hold greater promise as the basis for a successful trading system than many of the more arbitrary trading methods presented previously. Some of the traditional forecasting methods, however, have a limited number of models from which to choose and, thus, are not able to adequately replicate the historical time series. Even when a wide range of models is available, there may still be no systematic way to select one particular model over another. For example, one of the problems in trading commodity futures contracts based on the exponential smoothing method is selecting the smoothing

factor (Barnes, 1979). With excessive smoothing, the forecasts will lag the actual data, while too little smoothing results in forecasts that fluctuate violently and cause whipsaw losses. With no systematic means of determining the appropriate smoothing model, judgment and trial-and-error play important roles in model selection. The Box-Jenkins approach overcomes these disadvantages, but model identification with Box-Jenkins can, nevertheless, be a cumbersome process.

With forecasting methods based on statistical models, there is also the issue of whether or not the price series behaves according to the random walk theory. This question is explored more fully in Chapter Two.

1.3 Research Objective

This research focuses on price forecasting as a basis for trading in futures markets. More specifically, the objective of the research is to develop a profitable system for trading futures contracts using the state space modelling and forecasting approach. Simulated trading of copper and gold futures contracts is conducted to evaluate the effectiveness of the technique. Major advantages of state space include the ability to introduce economic theory into the model structure, as well as the relative ease with which the model can be identified and estimated. Thus, a state space forecasting approach to futures trading would

incorporate some of the positive features of the fundamental and technical analysis techniques described above.

1.3.1 State Space Models

State space forecasting originated in the mid-1970's with the work of H. Akaike who created the method from models used by engineers since the 1960 development of the Kalman filter (Goodrich, 1989). Following Goodrich (1988, 1989), a state space model can be expressed in canonical form

$$(4) \quad x_{t+1} = Fx_t + Ke_t \quad (\text{updating})$$

$$(5) \quad y_t = Hx_t + e_t \quad (\text{observation})$$

where: x_t = $nx1$ state vector

n = order of the model

y_t = $rx1$ endogenous vector

e_t = $rx1$ vector of one-step-ahead forecast errors

F = nxn transition matrix

K = $nx1$ Kalman gain matrix

H = $1xn$ measurement matrix

The state vector is the information from the past that is necessary to forecast the future of the process. A state space model of order, n , can be shown to be equivalent to an ARMA (n,n) model. Also, the counterpart to an ARMA (p,q) model is the state space (max (p,q)) model. As an example, consider an ARMA (1,1) model

$$(6) \quad y_t = \phi y_{t-1} - \theta e_{t-1} + e_t$$

For simplicity of notation, let $\phi = a$ and $-\theta = b$. Therefore,

$$(7) \quad y_t = a y_{t-1} + b e_{t-1} + e_t$$

There are three things to be aware of in the derivation of the state space equivalent to an ARMA (1,1) model. The first is that in (7), y_t is a realization; it is not a forecast. Second, state space is designed, *a priori*, to provide a forecast. Third, in time series analysis, the convention is that

$$(8) \quad y_t - \hat{y}_t = e_t$$

With these facts and definitions in mind, increment t in (7) by one period, giving

$$(9) \quad y_{t+1} = a y_t + b e_t + e_{t+1}$$

Then using the identity

$$(10) \quad y_{t+1} - \hat{y}_{t+1} = e_{t+1}$$

but replacing \hat{y}_{t+1} by $y_{t+1|t}$, we have

$$(11) \quad y_{t+1|t} = a y_t + b e_t$$

where $y_{t+1|t}$ is a forecast of y for $t+1$, given data up to time, t . An infinite number of predictors are possible, but the dimension of the predictor space is determined by the first n predictors that are linearly independent. The forecast of y for $t+2$ is

$$(12) \quad Y_{t+2|t} = aY_{t+1|t} + be_{t+1}$$

As seen in (12), the second predictor is linearly dependent upon the first, so the predictor space is of dimension 1. Equation (11) is in state space form, and by resubstituting for a and b

$$(13) \quad Y_{t+1|t} = \phi Y_t - \theta e_t$$

The canonical state space model

$$(14) \quad X_{t+1} = FX_t + Ke_t$$

requires state vector, x_t ; transition matrix, F ; innovation matrix, K ; and error vector, e_t . The canonical form for the state space equation (13) is the following:

$$X_{t+1} = F \cdot X_t + K \cdot e_{t+1}$$

$$(15) \quad \begin{bmatrix} Y_{t+1} \\ Y_{t+2|t} \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ 0 & \phi \end{bmatrix} \begin{bmatrix} Y_t \\ Y_{t+1|t} \end{bmatrix} + \begin{bmatrix} 1 \\ -\theta \end{bmatrix} e_{t+1}$$

Equivalently,

$$(16) \quad Y_{t+1} = Y_{t+1|t} + e_{t+1} \Rightarrow Y_{t+1} - Y_{t+1|t} = e_{t+1} \Rightarrow Y_{t+1} - \hat{Y}_{t+1} = e_{t+1}$$

$$(17) \quad Y_{t+2|t} = \phi Y_{t+1|t} - \theta e_{t+1}$$

The ARMA form of the model can be recovered. Decrementing indices $t+2$ and $t+1$ by 1

$$(18) \quad Y_{t+1|t} = \phi Y_t - \theta e_t$$

and using (16)

$$(19) \quad y_{t+1} - e_{t+1} = \phi y_t - \theta e_t$$

Or,

$$(20) \quad y_{t+1} = \phi y_t - \theta e_t + e_{t+1}$$

Decrementing indices $t+1$ and t by 1

$$(21) \quad y_t = \phi y_{t-1} - \theta e_{t-1} + e_t$$

This is the ARMA (1,1) model, where y_t is a realization.

The model can be expanded to include exogenous variables

$$(22) \quad x_{t+1} = Fx_t + Gz_{t+1} + Ke_t$$

$$(23) \quad y_t = Hx_t + e_t$$

with z_t being a $q \times 1$ exogenous vector and G an $n \times q$ exogenous effects matrix.

Forecasts are made using the Kalman filter form and initially setting the forecast error to zero. Observations through time, t , are used to estimate x_{t+1} , and the state forecast then provides the basis for generating the forecast of the observation:

$$(24) \quad y_{t+1|t} = Hx_{t+1|t}$$

As the next observation becomes available, the forecast error is computed

$$\begin{aligned}
 (25) \quad e_{t+1} &= y_{t+1} - y_{t+1|t} \\
 &= y_{t+1} - Hx_{t+1|t}
 \end{aligned}$$

The forecast error is used to update the estimate of x_{t+1}

$$(26) \quad x_{t+1|t+1} = x_{t+1|t} + Ke_{t+1}$$

and the process is then repeated. The parameter estimates are made using canonical correlation analysis, a procedure for extracting the intercorrelations of one set of random variables with another set (e.g., between past and future domains).

In the 1979 ORSA/TIMS forecasting tournament, state space models outperformed the other time-series methods (Mehra, 1982). To date, however, the application of the state space approach to commodity futures markets has been limited. Most of the relevant studies examined forecasting performance, but did not consider whether state space modelling and forecasting could provide the basis for a profitable trading system. One study (Rankin, 1986) used the Kalman filter method in developing and testing a trading strategy for the Dow Jones Transportation (DJT) index, but the only variable considered was the price series for the DJT. By contrast, a multivariate approach is being proposed for this research.

The study, therefore, will involve the development of a different approach to trading commodity futures. In

addition, the research will contribute to the empirical evidence concerning the efficiency of futures markets, particularly the copper and gold futures markets. Since multivariate state space models will be used to forecast prices, the analysis will be in the framework of a semi-strong test of market efficiency (defined in Chapter Two) rather than the usual weak form tests which rely only upon past prices.

1.3.2 Basis for Selecting Copper and Gold

Copper was selected for analysis, since it can be considered a conventional commodity whose price is largely determined by the interaction of supply and industrial, rather than investment, demand. Price formation in the gold market, on the other hand, is thought by many to be influenced by investment demand related to international macroeconomic factors. The research will, therefore, examine the applicability of state space modelling and forecasting to both types of markets.

1.4 Outline of the Study

Chapter One has described the more well-known trading systems used in commodity futures markets, along with their advantages and limitations. In addition, the state space forecasting approach, the focus of this research, was introduced. The research methodology for the study is

presented in Chapter Two. In that chapter the market efficiency issue is also examined and recent applications of state space models to commodity futures markets are discussed. Chapter Three contains the results of the simulated trading and shows the profitability, by contract, of the different trading strategies which are tested. Chapter Four summarizes the study and includes suggestions for further research.

CHAPTER TWO

RESEARCH METHODOLOGY

2.1 Market Efficiency

An important question which relates to most, if not all, of the trading systems described in Chapter One is whether or not the market in question is efficient; that is, to what extent do prices fully reflect all available information. A framework for analyzing market efficiency and more rigorously defining what is meant by "fully reflect" has been provided by Fama (1970).

Early studies of market efficiency focused on what are known as weak form tests where the information set includes only past prices or returns. Subsequently, attention turned to semistrong tests which measured how quickly prices respond to all publicly available information, and finally to strong form tests which analyzed whether any individuals or groups have monopolistic access to information, giving them a trading advantage.

The weak form tests of the stock market which Fama reviewed led him to the conclusion that the efficient markets hypothesis could not be rejected. There was some evidence of dependence in successive price changes in some markets which could be used to develop marginally profitable trading rules. The potential profits would, however, be exceeded by the commissions which would have to be paid on the many

transactions generated by the trading rules.

Semistrong tests, according to Fama, cannot reject the efficient markets hypothesis. Expectations about a firm's future dividend payments after a stock split have been shown to generally have been fully reflected in the share price by the time of the split. Similar results were reported relative to information contained in annual earnings announcements and new and secondary issues of common stocks.

Departures from market efficiency can, nevertheless, be observed in strong form tests. For example, the specialists on major stock exchanges (and floor brokers on futures exchanges) have information on unexecuted trading orders which can be used to generate trading profits. Similarly, corporate insiders have access to information not available to the general public.

Fama lists the sufficient, but not necessary, conditions for capital market efficiency:

- 1) there are no transactions costs in trading
- 2) all available information is accessible without cost to market participants
- 3) all agree on the implications of the information on the current price of the security

Fama maintains that, although these conditions are not met in practice, the empirical evidence has not demonstrated that any such deviations could lead to the development of

consistently profitable trading rules, as would be the case if the efficient markets hypothesis were to be rejected. Other empirical studies have since been conducted on the question of whether successive price changes are uncorrelated as would be indicated by the random walk model, but they have not provided an unambiguous answer to the market efficiency issue. The following sections describe research that has been performed on the efficiency of the copper and gold markets.

2.1.1 Efficiency of Copper Markets

With few exceptions, most research on the efficiency of copper markets seems to support the efficient market hypothesis. Gross (1988) examined the efficiency of copper and aluminum markets at the London Metal Exchange (LME) with a data set consisting of 439 daily cash and 3-month forward prices observed during 1983 and 1984. Because copper and aluminum are substitutes in a number of applications, a simultaneous equation model was employed which incorporated price information for one commodity into the price forecasting equation for the other commodity. The mean squared forecast errors (MSE) for the price forecasting models were not significantly less than the MSE for futures prices, so he concluded that the efficient market hypothesis cannot be rejected for copper or aluminum.

Making a similar comparison of the forecasting errors of

an econometric model with those of futures prices, Gupta and Mayer found no evidence of inefficiency in the copper futures market (ibid.). Labys and Granger (1970) applied spectral analysis to the monthly futures prices of 13 commodities, including copper, over the 1950-1965 period. Although there was some evidence of a seasonal component to the price series, they could not reject the random walk hypothesis for copper.

Goss approached the market efficiency question from a somewhat different perspective, as he analyzed the correlation between the forecasting errors of closely related commodities and concluded the efficient market hypothesis should be rejected for copper (Gross, 1988). Gross, however, takes issue with this conclusion on the basis that new information becoming available could cause the prices of several metals to move in the same direction, leading to correlation in the forecasting errors. Thus, the efficient market hypothesis could mistakenly be rejected.

2.1.2 Efficiency of Gold Markets

As with copper, research conducted to date has provided little evidence that a profitable trading system can be developed by exploiting inefficiencies in the gold market. In a 1980 study, Abken analyzed how quickly the gold market responds to new information. He regressed the percentage change in the first-of-month gold prices (P.M. fixing on the

London market) on current interest rates and the percentage change in gold prices for previous periods. The results of this and additional tests he conducted indicate that information is rapidly incorporated into spot prices, implying efficiency in the gold market.

Booth, Kaen, and Koveos (1982) used a technique called rescaled range analysis (R/S) to test for dependence in daily Handy and Harman gold prices over the period February 1969 to March 1980. They found that the gold return series, which was represented by the first differences in the natural log of daily gold prices, was characterized by positive long-term dependence and that cycles of unequal duration were present. The authors suggest that a profitable trading strategy might be developed based on these findings, but no attempt was made to formulate one.

Koutsoyiannis (1983) developed a constant-supply, speculative market model for determining the price of an asset such as gold. A price function was derived by equating gold demand and supply and then solving for the equilibrium price. Incorporated into the model were prices of alternative assets (the foreign exchange rate, the prime interest rate, the price of silver, and the Dow Jones index of stock prices), inflation-related variables (the consumer price index and the spot price of Saudi crude oil), an index of political tension, and the lagged price of gold. The data

covered 316 daily observations from December 1979 to March 1981, and gold prices were represented by the afternoon fixing on the London market. The model was estimated in linear and log-linear form using ordinary least squares, and all coefficients had the expected sign.

Most coefficients were significant at the 1 percent level, but the null hypothesis for the coefficient for the Dow Jones index could be rejected only at the 20 percent significance level. The elasticity of the Dow Jones index was also quite low, indicating minimal substitution between these assets. Since the coefficient for the lagged price of gold was statistically significant, Koutsoyiannis suggests that speculators are unwilling to react immediately to all available market information, and, therefore, the gold market is inefficient in the very short run. Like Booth, Koutsoyiannis did not try to develop a trading strategy based on her model.

Solt and Swanson (1981) employed autocorrelation and runs tests in their study of the efficiency of the gold and silver markets. The price series for each commodity was based on the Friday afternoon fixing on the London market over the period January 1971 to December 1979. The autocorrelation coefficients suggested a positive relationship for successive price changes. The number of runs, the sequences of price changes in the same direction

preceded and followed by changes in the other direction, also was less than would be expected for sequences of random numbers. Solt and Swanson tried different trading rules and determined that investors would not be able to use the positive dependence in the price series to generate higher profits than a buy-and-hold strategy.

Using regression analysis and data covering the period 1975-1985, Neal (1988) tested for informational efficiency in the gold futures market. The test was of the semistrong variety in that it considered publicly available information beyond just the price series. The monthly forecast error, the difference between the future spot price and the current futures price, was regressed on selected information variables, and the equation was of the form

$$(27) \quad S_{t+1} - F_t = \alpha_0 + \alpha_1 X_{1t} + \alpha_2 X_{2t} + \dots + \alpha_n X_{nt} + e_{t+1}$$

where: S_{t+1} = spot price of gold one month in the future

F_t = current futures price

X_{nt} = current value of the n th informational variable

e_{t+1} = regression error term

The informational variables were those expected to have a significant influence on the price of gold, including interest rates, exchange rates, stock prices, and the producer price index. The forecast error was regressed on different subsets of the informational variables, and since it was not a true structural model, individual coefficients

and t -statistics were ignored and the F -statistic was used to determine the extent of the dependence of the forecast error on a set of variables as a group. The F -statistics for 6 of the 10 regressions were significant at the 5 percent level, but the coefficients of multiple determination (R^2) for all were low (less than 0.16).

Two mechanical trading rules were applied to determine whether using the informational variables could generate above average profits. One rule was to buy a contract when the predicted value of $S_{t+1} - F_t$ was positive and sell one contract when the predicted value was negative. The second rule was similar to the first, but the number of contracts purchased or sold varied according to the strength of the signal. Both strategies resulted in losses even before commissions were considered. Neal, therefore, concluded that the gold futures market is informationally efficient, since consistent profits could not be made by employing either strategy.

Although Neal's study is similar in some respects to this research, the application of the state space approach and the use of daily, rather than monthly, data provides an enhanced semistrong test of informational efficiency in the gold futures market.

2.2 State Space Models in Commodity and Financial Markets

To date, the application of the state space approach to

forecasting prices in commodity or financial markets has been limited. Bossaerts (1986) used state space models to examine the efficiency of foreign exchange markets. He concluded that the first differences of spot foreign exchange rates appeared to follow a random walk, and he then regressed the change in the spot rate on the forward premium, the difference between the forward foreign exchange rate at t and the spot foreign exchange rate at t , to determine whether the forward premium contains information beyond that available in just the spot rate changes. For six of the seven currencies analyzed, the regression coefficients were significantly different from zero, leading to the conclusion that the forward premium does incorporate more information than is present in the spot foreign exchange rate and that the forward market is semistrong efficient. (Bossaerts, therefore, appears to define efficiency in the semistrong sense somewhat differently than Fama and other authors.)

The changes in spot foreign exchange rates were then estimated using the forward rate to update the state vector. Error statistics were computed from the one-step-ahead forecast errors for both the state space and random walk models, and the state space model was shown to outperform the random walk model.

Rankin (1986) used the state space approach to forecast intraday stock and commodity prices. To produce effective

forecasts, a statistically significant autocorrelation pattern must exist which can be modelled. (In a discussion of multivariate ARIMA models, McCleary and Hay (1980) show, however, that, even when a particular series follows a random walk and the best univariate forecast of the future price is the current price, the addition of a causal variable to the model can result in a significant improvement in forecast performance.) The autocorrelation and partial autocorrelation functions were used to determine whether a correlation pattern existed in various stock index and commodity price time series. Based upon the superior correlation statistics, the Dow Jones 20 Transportation (DJT) index, sampled hourly, was carried forward to the forecasting phase.

One-step-ahead forecasting of the DJT was conducted using Gauss-Markov and ARIMA (1,1,1) models converted to state space form. The ARIMA models were tested with both the standard Kalman filter and the adaptive Kalman filter. For all three DJT series, the state space forecasts resulted in a smaller mean squared error (MSE) than the random walk model, with the adaptive Kalman filter providing better results than the basic filter in each case.

Rankin then developed different buy/sell strategies to determine if using the DJT forecasts generated from the adaptive Kalman filter could increase profits over the buy-

and-hold strategy. Four speculator strategies were considered, and, ignoring commissions, all of them outperformed the buy-and-hold approach for the three DJT series. Nevertheless, with a commission rate of 0.25%, only one system proved profitable for any of the data series and it did not consistently outperform the buy-and-hold strategy.

Koss (1985) looked at alternative time series models of three monthly agricultural commodity price series: slaughter steers (January 1925-August 1983), heifers (January 1935-August 1983), and cows (January 1910-May 1983). Prices were expressed in dollars per hundred-weight, and the monthly producer price index was used to deflate all series. Data from 1975-1983 were reserved for predictive tests of the models.

For the univariate series, the alternative models were based upon the Box-Jenkins technique, the frequency domain approach, and the Kalman filter method. The estimates generated by the different methods were similar, but the Kalman filter method was preferable in terms of minimizing the variance of the prediction errors, so the Kalman filter was used in forecasting.

Two multivariate models were also constructed. One was based on the univariate model supplemented by variables which theory and institutional information have indicated to be of value. The other was a model established purely on

statistical relationships in the raw data with no theoretically-based restrictions. Stepwise regressions were performed, and some of the variables in the regressions were transformed using parameters from the Kalman filter estimation of the appropriate univariate price equation.

For all three models, a series of 1 month, 6 months, 12 months, and 18 months-ahead forecasts were made. The results indicated that the multivariate model containing theoretically-based restrictions consistently outperformed the univariate model, especially with an increasing forecast horizon. The same did not hold, however, for the unrestricted multivariate model. For steers and heifers, the multivariate model was outperformed by the univariate models. For cows, the multivariate model without restrictions achieved better results than both the univariate and restricted multivariate models.

State space models were used by Banerjee (1985) to test whether cattle futures trading or the introduction of external information through joint trading in unrelated commodities has a destabilizing influence on weekly cattle cash price changes. The addition of a futures market cannot affect cash prices through the introduction of new information unless the futures market facilitates cross-futures or joint trading in unrelated commodities, permitting external information inflows. Banerjee's findings were that

external information, as represented by price data on commodities unrelated to cattle, and the cattle futures market were not responsible for instability in spot cattle prices.

Using three-month forward prices on the London Metal Exchange (LME), Hsieh and Kulatilaka (1982) tested the hypothesis that forward prices equal the traders' expectations of spot prices at the maturity date of the forward contract. Because price expectations cannot be observed, two different models of expectations formation were employed. For one model, traders were assumed to have full-information rational expectations, while in the second model, expectations were developed from a "mechanical" predictor such as the Kalman filter.

With no risk premium, defined as the difference between the forward price and the expected future spot price at maturity of the forward contract, forward prices should have a lower mean squared error than the Kalman filter in forecasting future spot prices. Four commodities were analyzed: copper, tin, lead, and zinc, and the Kalman filter forecasts of future spot prices performed better than forward prices, suggesting that forward prices do, indeed, contain nonzero risk premia.

2.3 Selection of Futures Contracts

There are numerous types of contracts being traded on

futures exchanges, but the emphasis for this study is on copper and gold futures. The largest volume of trading in metals futures contracts in the United States occurs at Commodity Exchange, Inc. (COMEX) in New York, so the research focuses on copper and gold futures contracts traded on COMEX.

Trading in gold futures contracts on COMEX is conducted in the current calendar month, the next 2 months, and any February, April, June, August, October, and December falling within a 23-month period beginning with the current calendar month (COMEX, various years). The trading unit for a gold futures contract is 100 troy ounces of refined gold assaying not less than 0.995 fineness. Price changes for the contract are registered in multiples of \$.10 per troy ounce.

Copper futures contracts are also traded in the current and next 2 months, as well as in any January, March, May, July, September, and December within the same 23-month period (*ibid.*). A copper futures contract is for 25,000 pounds of electrolytic or certain types of fire-refined copper with Grade 2 electrolytic cathode copper the basis grade for the contract. (Beginning 1989, Grade 1 electrolytic cathode copper became the basis grade.) Price changes for copper futures contracts are registered in multiples of \$.005 per pound.

To insure adequate trading volume, the research only considers contracts for delivery in the six primary trading

months specified above for each commodity. For both copper and gold, simulated trading is conducted on six different contracts with the contract expiration dates covering the years 1982-1987. The contracts selected for analysis have delivery dates in different years to avoid using the same data to determine model coefficients for different contracts. Evaluating contracts over a period of several years also facilitates the testing of trading strategies over varying economic conditions. Figures 1-12 show the settlement prices for the two commodities for the nine months prior to the expiration of each contract, and, as exhibited in these graphs, the price patterns differ considerably from one contract to the next. The contracts to which trading strategies are applied include:

Table 1. FUTURES CONTRACTS EVALUATED

<u>Copper Futures Contracts</u>	<u>Gold Futures Contracts</u>
January 1982	February 1982
March 1983	April 1983
May 1984	June 1984
July 1985	August 1985
September 1986	October 1986
December 1987	December 1987

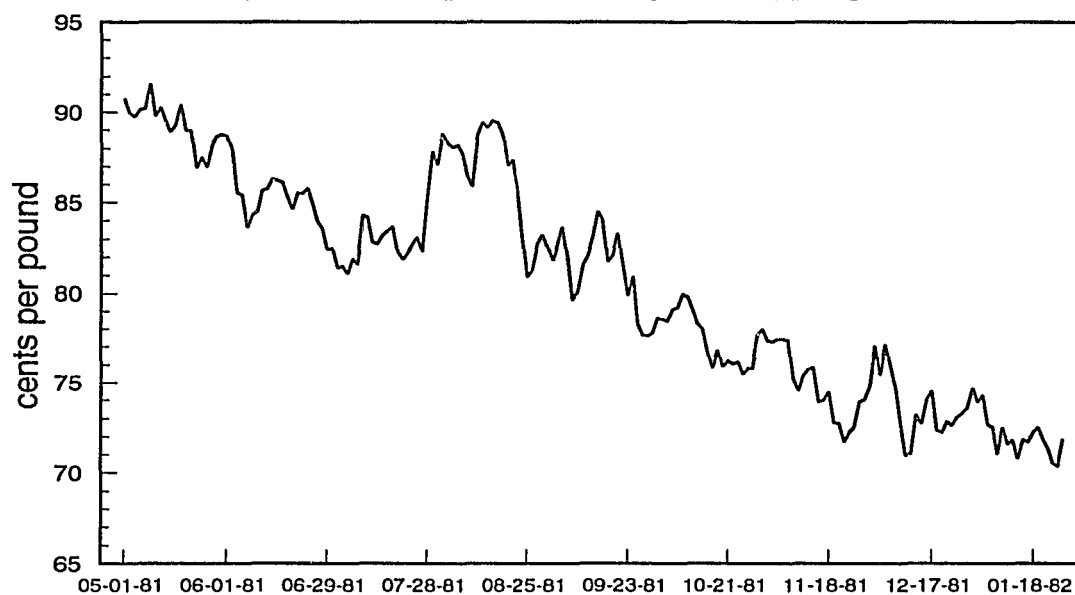
2.4 Simulated Trading of Copper and Gold Futures

For each contract, forecasts are made and simulated trading conducted over the last six months of the contract life. Much of the data for the variables included in the

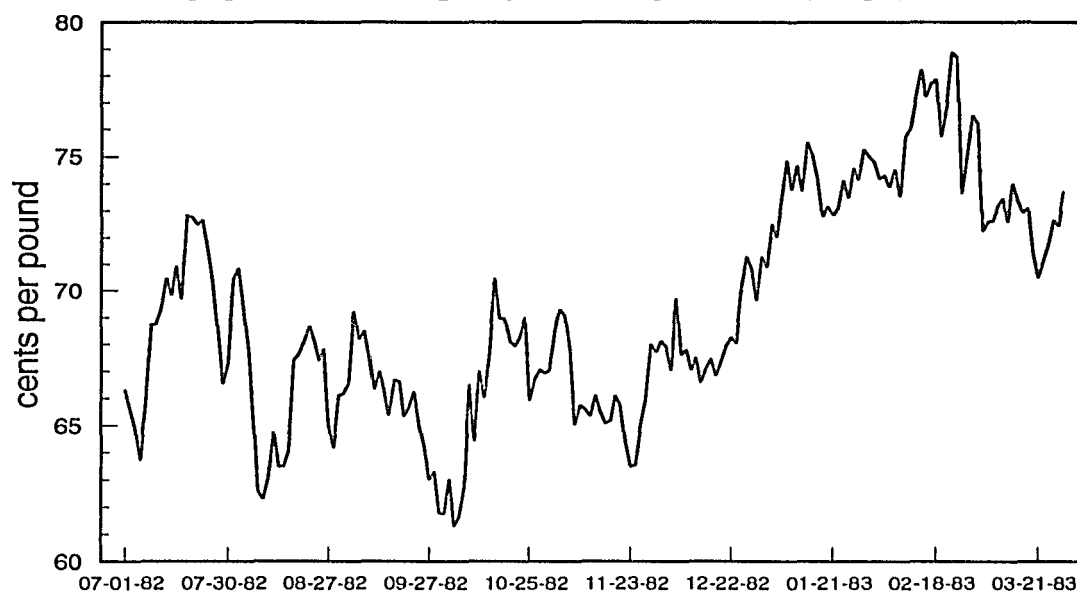
multivariate state space models is not available for time intervals shorter than one day. Therefore, the simulated trading uses the data reported at the close of the markets one day to forecast the next day's settlement price. The initial and succeeding state space models are based on the 60 observations prior to the forecast. The variables selected for inclusion in the model depend upon that combination which yields the highest R^2 . The model parameters are reestimated every day, and on the first trading day of each week, the model is evaluated to determine whether some variables should be added or dropped.

Modelling and forecasting are performed using *Forecast Master Plus*, a forecasting package developed for personal computers by Business Forecast Systems, Inc. of Belmont, Massachusetts. Variables are transformed to achieve stationarity which involves taking the first differences of the data series. Where necessary, a seasonal model is fitted to obtain acceptable residual statistics.

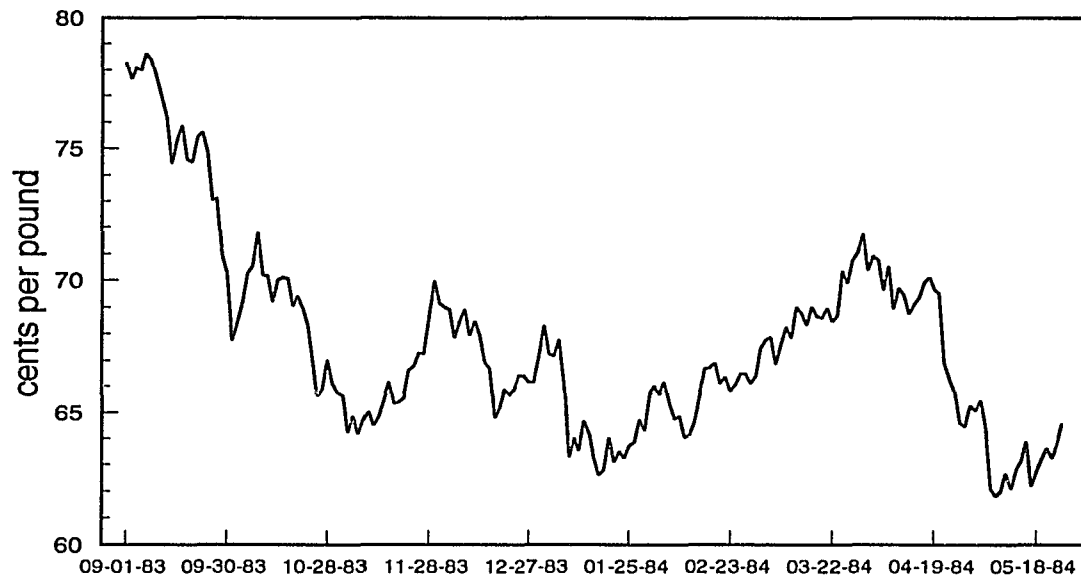
For state space modelling, *Forecast Master Plus* treats variables in one of two ways. The first option considers all but the first variable as exogenous, so to forecast the futures price, it is necessary to provide forecasts for the exogenous variables. The other option, the one selected for this research, regards all variables as endogenous and, therefore, forecasts of the other variables do not have to be

Figure 1**SETTLEMENT PRICES FOR THE JANUARY 1982
COPPER FUTURES CONTRACT**

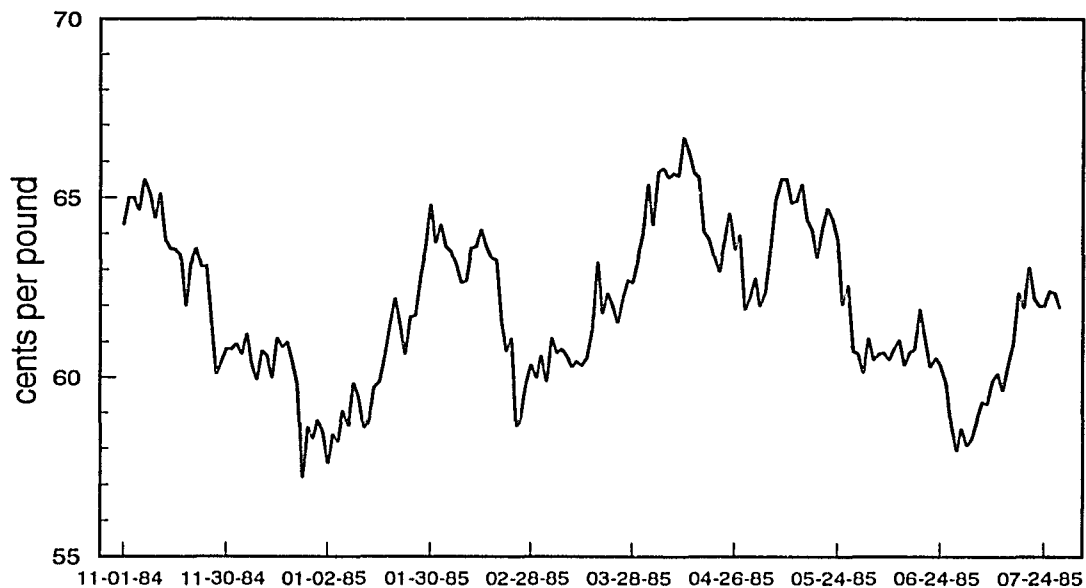
Source: COMEX, 1982 and 1983.

Figure 2**SETTLEMENT PRICES FOR THE MARCH 1983
COPPER FUTURES CONTRACT**

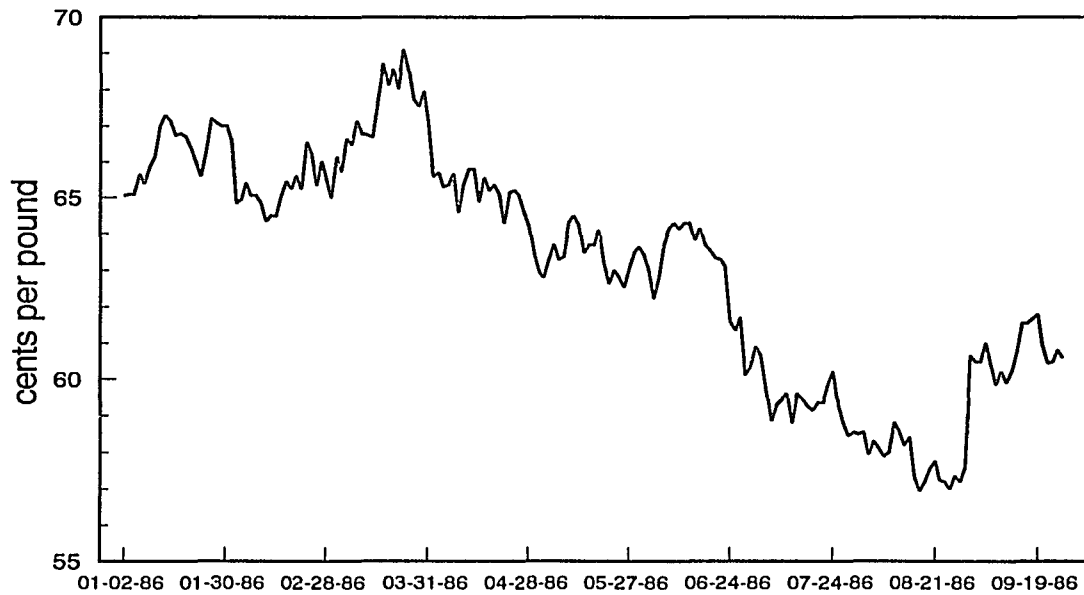
Source: COMEX, 1983 and 1984.

Figure 3**SETTLEMENT PRICES FOR THE MAY 1984
COPPER FUTURES CONTRACT**

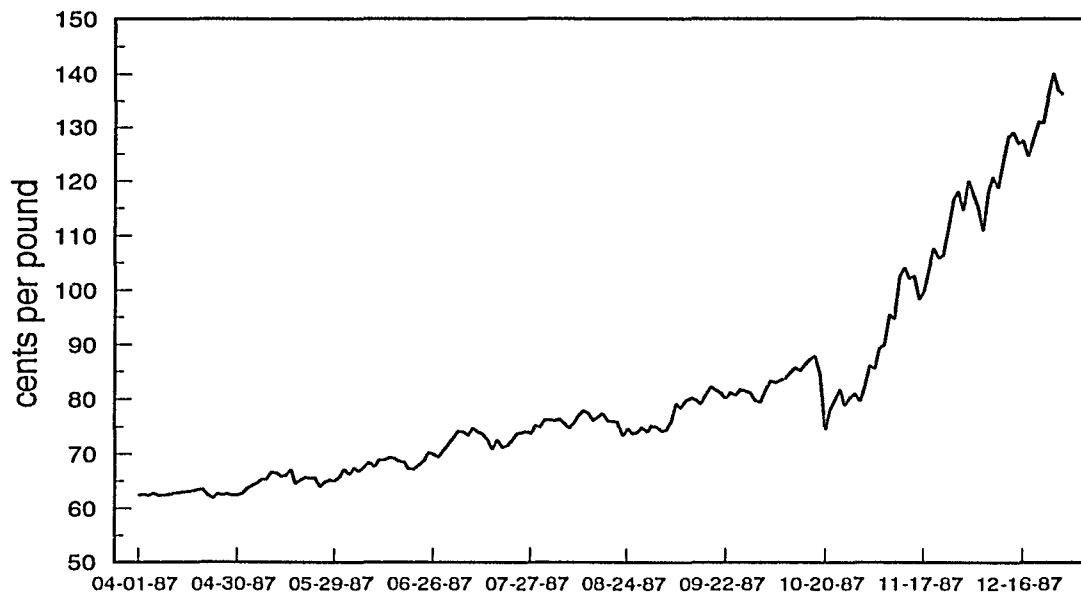
Source: COMEX, 1984 and 1985.

Figure 4**SETTLEMENT PRICES FOR THE JULY 1985
COPPER FUTURES CONTRACT**

Source: COMEX, 1985 and 1986.

Figure 5**SETTLEMENT PRICES FOR THE SEPTEMBER 1986
COPPER FUTURES CONTRACT**

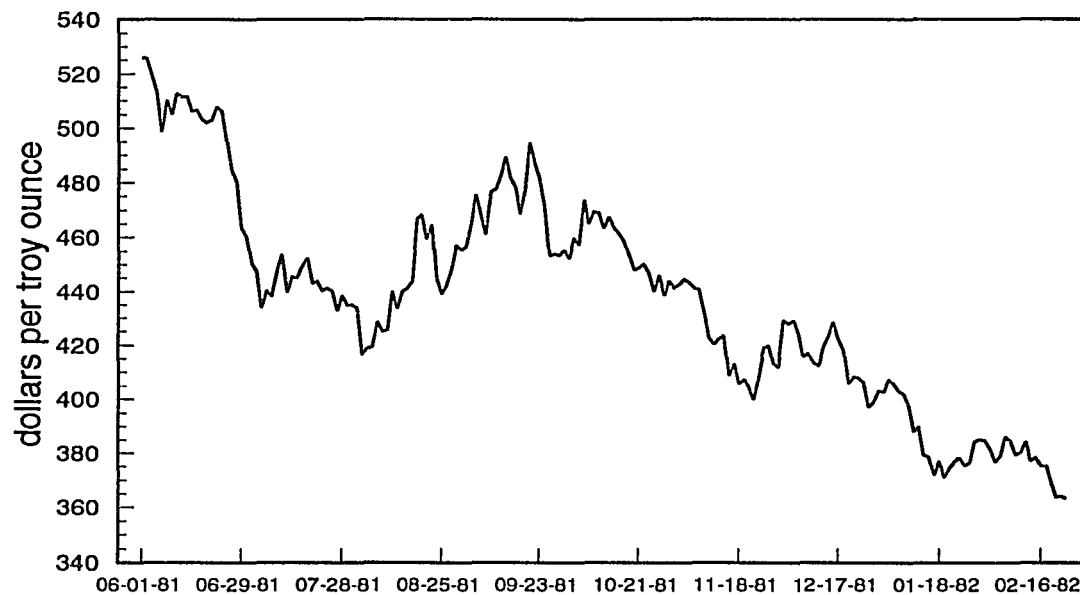
Source: COMEX, 1987.

Figure 6**SETTLEMENT PRICES FOR THE DECEMBER 1987
COPPER FUTURES CONTRACT**

Source: COMEX, 1988.

Figure 7

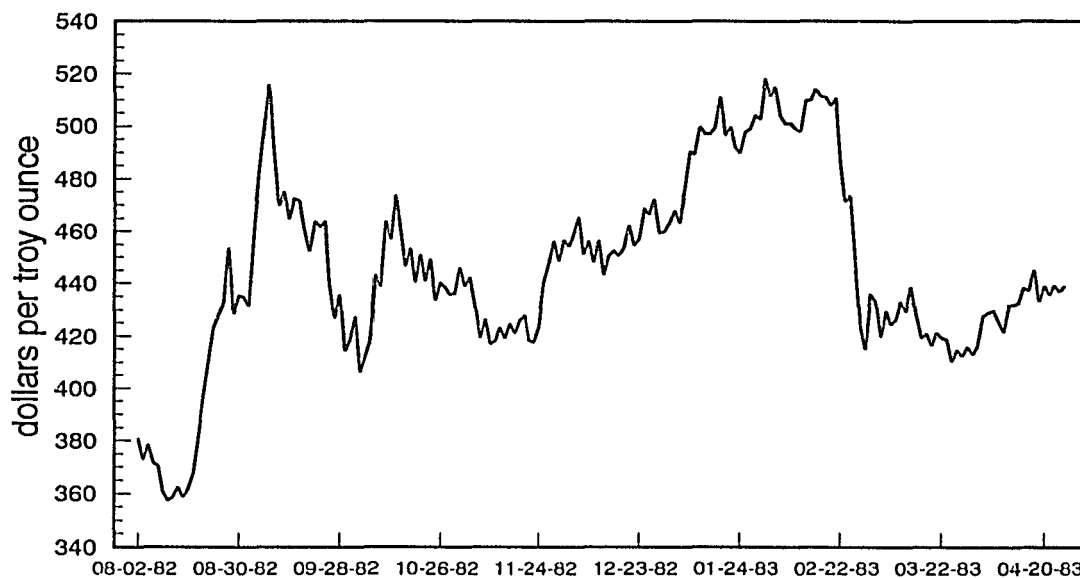
SETTLEMENT PRICES FOR THE FEBRUARY 1982 GOLD FUTURES CONTRACT



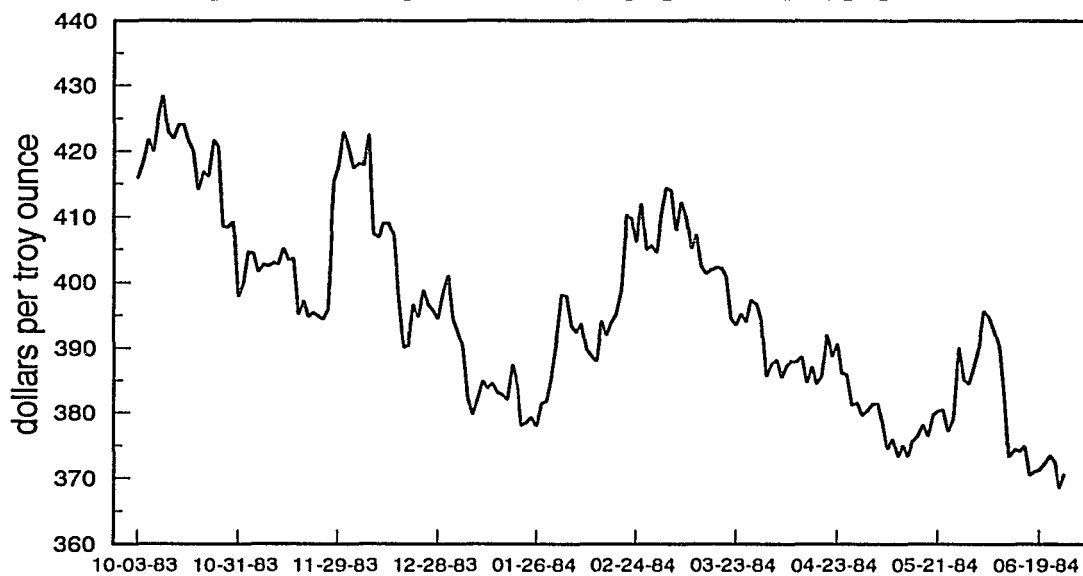
Source: COMEX, 1982 and 1983.

Figure 8

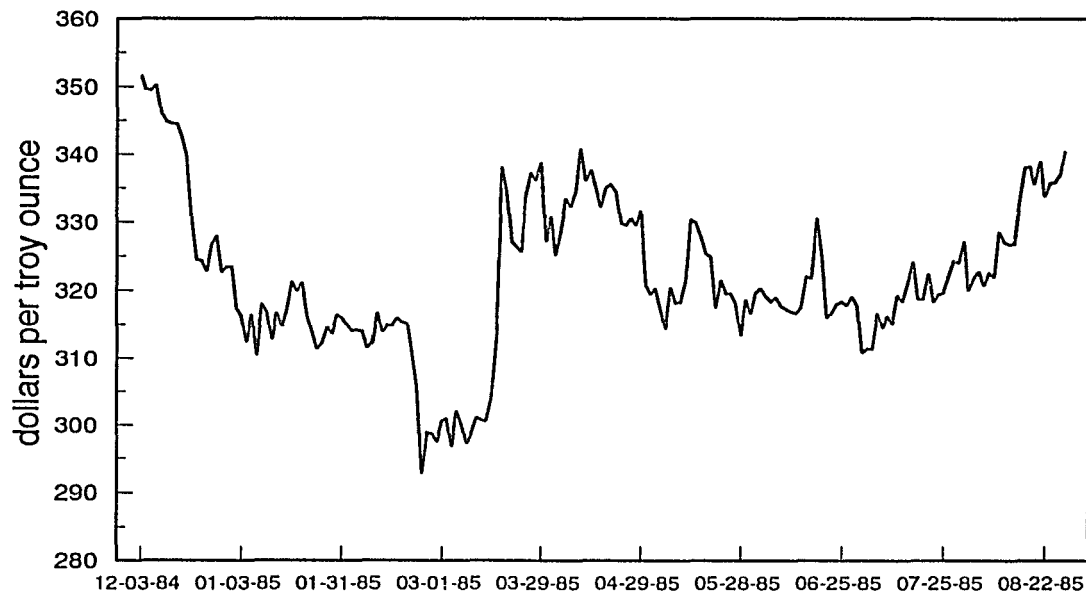
SETTLEMENT PRICES FOR THE APRIL 1983 GOLD FUTURES CONTRACT



Source: COMEX, 1983 and 1984.

Figure 9**SETTLEMENT PRICES FOR THE JUNE 1984
GOLD FUTURES CONTRACT**

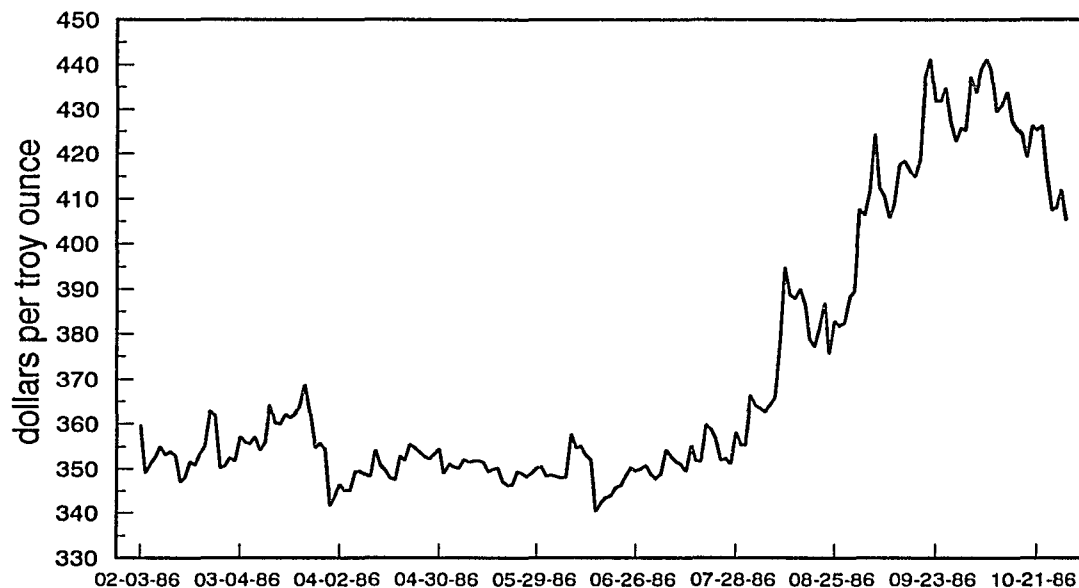
Source: COMEX, 1984 and 1985.

Figure 10**SETTLEMENT PRICES FOR THE AUGUST 1985
GOLD FUTURES CONTRACT**

Source: COMEX, 1985 and 1986.

Figure 11

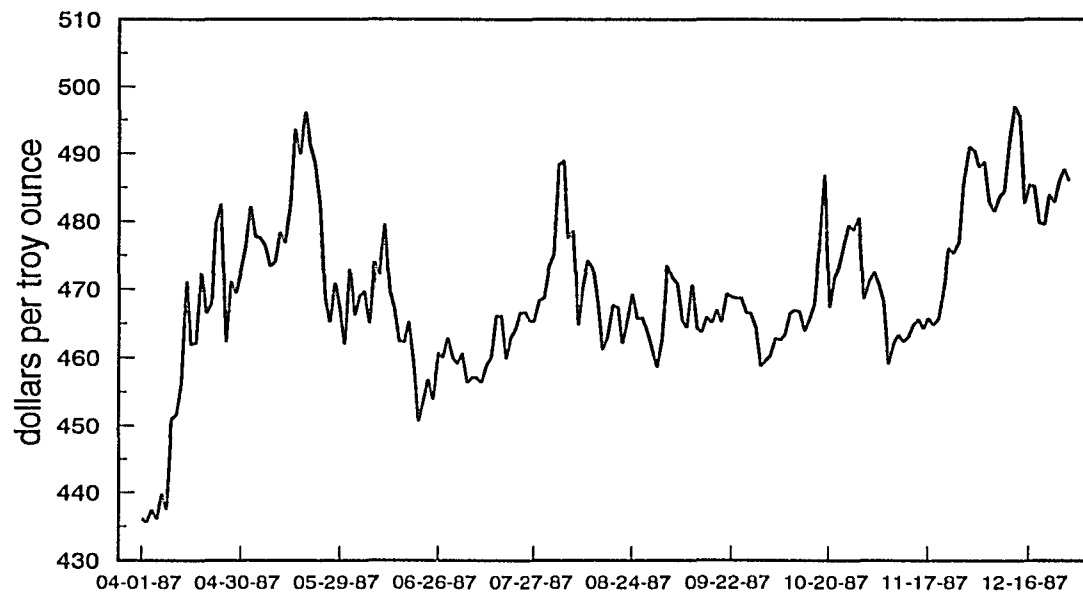
SETTLEMENT PRICES FOR THE OCTOBER 1986 GOLD FUTURES CONTRACT



Source: COMEX, 1987.

Figure 12

SETTLEMENT PRICES FOR THE DECEMBER 1987 GOLD FUTURES CONTRACT



Source: COMEX, 1988.

supplied. Forecasting of these variables is done implicitly within the model, and only lagged, not contemporaneous, values of the other variables are used to forecast the futures price.

2.4.1 State Space Models of Copper and Gold Futures Prices

As discussed above, the state space models of copper and gold futures prices consider factors which, based on economic theory, may influence price movements. Since gold is a speculative asset and copper is a nonspeculative commodity, the variables in the state space models of copper and gold futures prices are quite different.

Copper is used in building construction, power transmission, telecommunications, electrical and electronic products, industrial machinery, and transportation equipment. The demand for copper in these and other applications is considered a derived demand in that it is dependent upon the demand for final goods, such as automobiles, houses, or small appliances. Although the demand for copper could be modelled by analyzing individual end-use industries, the structural models of copper markets which have been developed, including those by Mikesell (1979) and Fisher, Cootner and Bailey (1972), tend to take a more aggregated approach by employing, for example, indices of industrial production or construction materials. These indices are, at best, only available on a monthly basis and then only after a considerable lag, so they

are not suitable for a trading system which relies on daily data. However, with copper demand closely related to level of industrial activity, the Dow Jones Industrials Average is used in the model as a measure of the strength of the economy.

The demand for copper would also normally be expected to be related to the price of substitutes, but the very short run nature of the state space models would likely preclude substitution to any degree. Nevertheless, aluminum is the principal substitute for copper in many applications, so to determine whether there is a relationship between prices of the two metals, the COMEX aluminum futures price is included in the model beginning with the May 1984 copper futures contract. (Aluminum futures contracts were not traded on COMEX until late 1983.)

Because of the short forecast horizon, copper supply is considered fixed in the models, and it is through changes in stocks that imbalances in the supply and demand for copper become evident. An important role in the determination of copper prices is then assigned to the volume of reported inventories held by producers, merchants, fabricators, and the LME and COMEX exchanges. Although copper warehouse stocks held at the LME and COMEX are not a complete measure of inventories, figures from these exchanges are available frequently (i.e., daily for COMEX and weekly for the LME).

The state space models of copper futures prices, therefore, include as variables for consideration LME and COMEX warehouse stock levels.

Gold also has many industrial applications, but its history as a store of value and a medium of exchange have resulted in a monetary role for gold that copper does not possess. It is investment, rather than industrial, demand which drives the price of gold, so factors which affect gold prices tend to be more macroeconomic in nature than those which influence copper prices. In a capital asset pricing model (CAPM) framework, gold prices move in response to changes in the prices of alternative assets, and portfolio adjustment decisions are made based upon the risks and returns of the individual assets and the risk preferences of investors.

In addition to the futures price, the forecasting model for gold considers such variables as the foreign exchange rate, the Treasury bill rate, and the federal funds rate. The exchange rate is included in the model, since, as the value of the dollar rises, dollar-denominated assets become more attractive due to their income-earning potential, causing the price of gold to fall. The exchange rate is represented in the model by the Federal Reserve Board's trade-weighted index of average exchange value of the U.S. dollar against the currencies of other G-10 countries. This

index was used rather than the exchange rate expressed in terms of an individual foreign currency in order to avoid modelling problems associated with circumstances which may be unique to a particular country.

Similar to foreign exchange rates, as U.S. interest rates increase, holders of gold shift funds to interest-bearing assets and the price of gold again declines. The rise in interest rates also tends to result in an increase in the value of the dollar, putting further pressure on gold prices. Interest rates are defined in the model as the yield on 6-month Treasury bills.

The federal funds rate, the interest rate on overnight loans from one depository institution to another, is the other variable considered in the state space models of gold futures prices. The federal funds rate is of such short duration that it is free from inflationary expectations and, therefore, can be viewed as the opportunity cost of investing in more long-term assets.

Gold is often viewed as a hedge against inflation, but because inflation indices are available no more frequently than every month, the rate of inflation is not explicitly included in the models. To a certain degree, however, inflationary expectations are incorporated into the models through the yield on 6-month Treasury bills.

2.4.2 Generation of Trading Signals

Once the modelling and forecasting are completed, a strategy is then developed to generate trading signals. Two different types of "filters" are tested. For the first filter, the initial trade is made when the percentage difference between the forecast for the next day's futures price and the current settlement price meets or exceeds a certain threshold.

$$\text{If } \frac{F_{t+1} - S_t}{S_t} \geq +\text{threshold \%} \Rightarrow \text{buy futures contract}$$

$$\text{If } \frac{F_{t+1} - S_t}{S_t} \leq -\text{threshold \%} \Rightarrow \text{sell futures contract}$$

Should a buy or sell signal be generated, the indicated trade is assumed to take place at the next day's settlement price. After that position is taken, should the threshold be met or exceeded in the opposite direction, the first trade is closed out and the opposite position taken. This continues for the remainder of the contract life. Therefore, once the first trade is initiated, a one-contract position (either long or short, depending upon the trading signal) is maintained until the expiration of the contract. This position limit of one contract is later relaxed, as explained in Chapter Three. Different percentage thresholds are tested ranging from 0.25%-0.50%, in increments of 0.05%.

The second type of filter is similar to the first, but to close out one trade and take the opposite position requires that the difference between the forecast and the last day's settlement price be twice the threshold for the initial trade. For both filters, commissions on all trades are assumed to be \$32 per round-turn (Lind-Waldock, 1990).

CHAPTER THREE

RESEARCH RESULTS

This chapter presents the results of the simulated trading of copper and gold futures contracts that was conducted using the state space modelling and forecasting approach described in Chapter Two.

3.1 State Space Models of Copper Futures Prices

The state space models of copper futures prices indicated that relevant market information is rapidly discounted into the futures price. For the six contracts analyzed, the state space models were overwhelmingly of order 1. Only one percent were of order 2 and none were a higher order.

Most of the explanatory power of the models was derived from the lagged value of the futures price and the error terms. Typically, there was little difference in the coefficient of determination (R^2) for models having distinct combinations of variables. Models with one variable (other than the copper futures price) produced the highest R^2 approximately 85 percent of the time with the remainder accounted for by two-variable models. In no case was a model containing three variables selected. (State space models with four additional variables could not be estimated on a personal computer with *Forecast Master Plus* due to the memory

requirements.) The R^2 for the 156 models constructed for the 6 contracts ranged from 0.53 to 0.97.

Figure 13

PERCENT OF TIME VARIABLES APPEARED IN THE STATE SPACE MODEL OF COPPER FUTURES PRICES

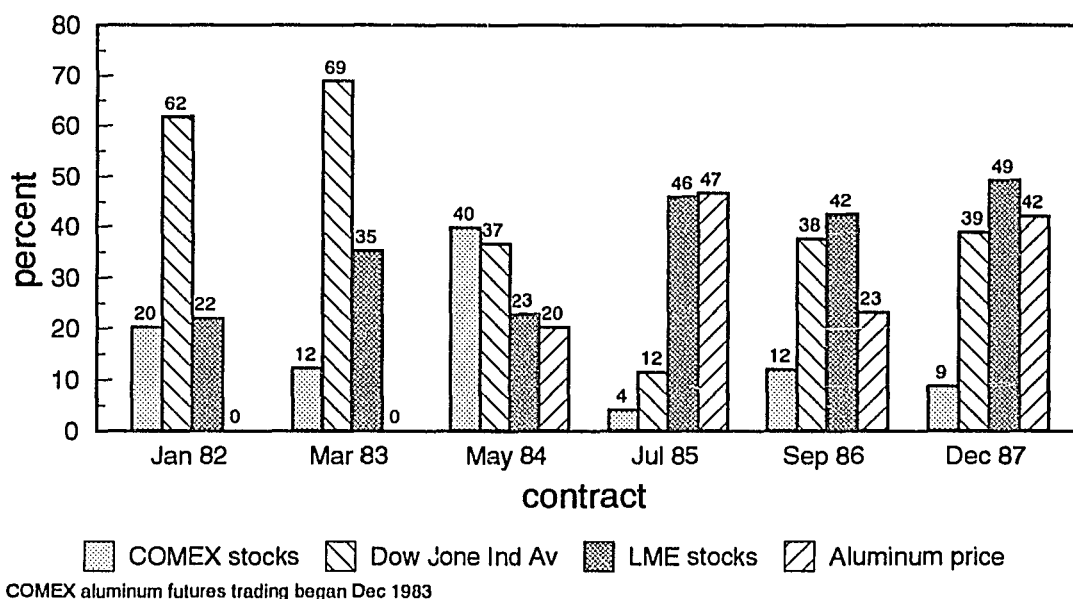


Figure 13 shows the relative frequency with which variables appeared in the state space models of copper futures prices. (The total can exceed 100 percent, because some of the models contained two variables.) The Dow Jones Industrial Average (DJIA) was important, particularly for the January 1982 and March 1983 contracts. World copper production exceeded consumption beginning in 1980 and the imbalance continued to grow through the recession years of 1982-1983 (Sutulov, 1986). This resulted in considerable

downward pressure on copper prices during much of the period covered by these two contracts. It would appear, then, that expectations of the strength (or weakness) of the economy as reflected in the DJIA played a more important role than usual in copper price formation during this period.

Of particular interest in Figure 13 is the dominance of LME stocks over COMEX warehouse stocks in the models. For five of the six contracts, LME stocks were included in the state space models more frequently than COMEX stocks, often by a significant margin. This could be attributable, at least in part, to periods when COMEX stocks were considered to be of low quality and unsuitable for consumers requiring higher grade copper. During such periods, COMEX stocks would not be truly reflective of market conditions. This situation resulted from the COMEX copper contract allowing delivery at a discount or premium of grades other than electrolytic cathode, the basis grade for the contract (Bureau of Mines, 1985).

Although LME stocks dominated COMEX stocks in the models, there were contracts when even LME stocks did not appear all that frequently in the models. One potential explanation for this is that LME stocks are held in warehouses in different countries, and the measure of total stocks used in the models may mask variations in the geographic distribution of those stocks. Thus, stocks could

appear to be adequate on an aggregated basis, but if they are distributed less than optimally among the warehouses, copper prices may rise, nevertheless.

The aluminum futures price tended to be moderately important to the models, which is somewhat surprising, since little or no substitution between the metals can occur over such a short period of time. A cursory examination of the state space model using the option of treating all variables but the copper futures price as exogenous revealed that the coefficient for the aluminum price was positive, suggesting that, although substitution may not be causing the aluminum futures price to appear in the model as frequently as it did, aluminum prices may, nevertheless, be correlated with the same factors that affect copper demand.

3.2 Simulated Trading in Copper Futures Contracts

Table 2 displays the number of trades, by contract, generated through the application of the state space forecasting method to copper futures trading. The results are shown for the two different filters described in Chapter Two and for varying threshold percentages for each filter. The figures in parentheses in the table represent the number of trades that were profitable after deducting commission charges.

With a position limit of one contract, relatively few trades were signalled for most of the copper futures

**Table 2. TOTAL NUMBER OF TRADES AND THE NUMBER OF
PROFITABLE TRADES (IN PARENTHESES) FOR SIMULATED
COPPER FUTURES TRADING**

Filter: Initial %/ Reversal %	Contract						
	Jan 1982	Mar 1983	May 1984	Jul 1985	Sep 1986	Dec 1987	Total
Filter 1 .25%/.25%	11 (3)	14 (7)	5 (1)	5 (2)	9 (3)	23 (11)	67 (27)
.30%/.30%	8 (3)	10 (6)	5 (1)	3 (1)	7 (2)	19 (10)	52 (23)
.35%/.35%	4 (1)	10 (5)	5 (2)	2 (1)	5 (1)	17 (7)	43 (17)
.40%/.40%	4 (1)	6 (2)	3 (1)	2 (1)	5 (2)	12 (5)	32 (12)
.45%/.45%	4 (1)	6 (3)	2 (1)	0 (0)	4 (3)	12 (5)	28 (13)
.50%/.50%	2 (1)	6 (3)	2 (1)	0 (0)	1 (1)	11 (4)	22 (10)
Filter 2 .25%/.50%	2 (1)	6 (3)	2 (1)	1 (0)	1 (1)	12 (5)	24 (12)
.30%/.60%	1 (1)	6 (5)	1 (1)	1 (1)	1 (1)	12 (6)	22 (15)
.35%/.70%	1 (1)	4 (3)	1 (1)	1 (0)	1 (1)	12 (5)	20 (11)
.40%/.80%	1 (1)	4 (3)	1 (1)	1 (0)	1 (1)	7 (2)	15 (8)
.45%/.90%	1 (1)	4 (3)	1 (1)	0 (0)	1 (0)	7 (2)	14 (7)
.50%/1.0%	1 (1)	4 (3)	1 (1)	0 (0)	1 (1)	5 (1)	12 (7)

contracts which were analyzed. During periods when prices were essentially following a random walk, the state space forecast of the next day's futures price was little different from the current price. Thus, the forecast percentage change

in the copper futures price fell below the threshold level that would signal a trade. Filter 2 resulted in fewer trades than Filter 1 due to the more stringent requirement for a reversal of position, and the number of trades also declined, of course, as the threshold percentage was increased for either filter.

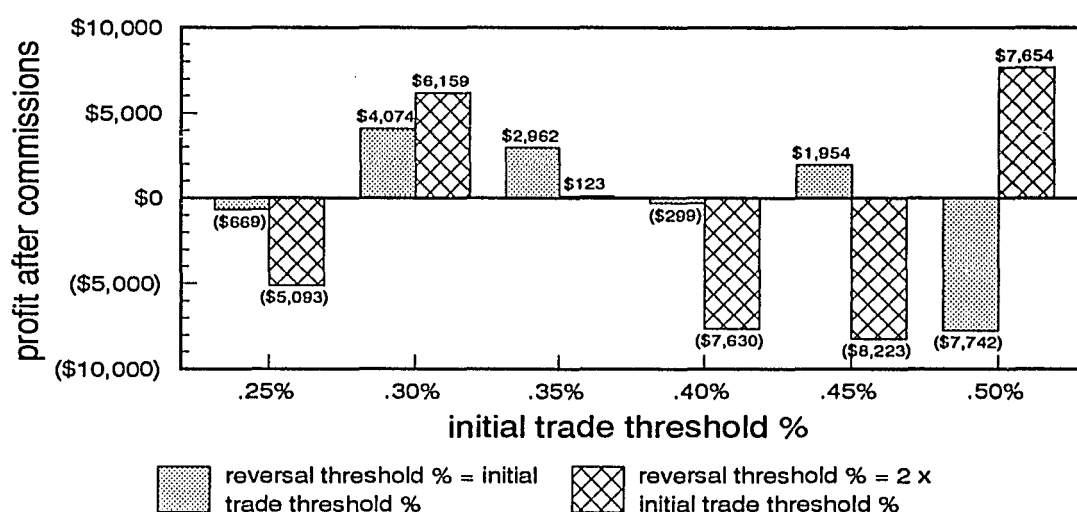
To be consistently profitable, any trading system should be able to prevent "whipsaw" losses associated with the generation of trading signals from random fluctuations in prices, but not be so restrictive as to forego significant profits by entering the market too late. As Table 2 indicates, there was a distinct difference in the rate of profitable trades for the two filters which were tested. For the filter having identical thresholds for the initial trade and reversal of position (Filter 1), profitable trades accounted for less than 50 percent of the total number of trades, while, for Filter 2, where a reversal of position required that the percentage change in the forecast over the current price be twice that for the initial trade, at least 50 percent of the total trades at each threshold were profitable.

Both filters realized positive profits for three of the six different threshold percentages (Figure 14), but some of the losses incurred at the other thresholds were rather sizable, particularly for Filter 2. The poor performance for

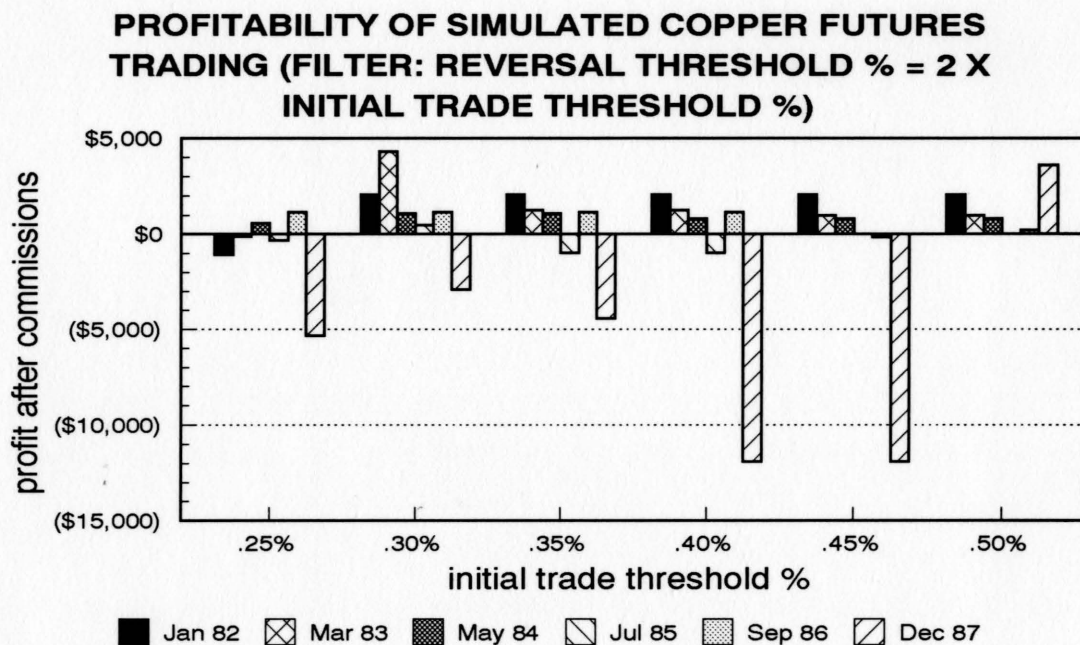
the three threshold percentages for that filter was almost entirely attributable to trades made during the December 1987 contract. This is evident in Figure 15 which shows the profitability for the individual contracts for Filter 2.

Figure 14

TOTAL PROFITS FOR ALL COPPER FUTURES CONTRACTS USING TWO FILTERS



Two separate sharp drops in price during a period dominated by almost continuous price increases resulted in signals to sell futures contracts. Prices, however, rapidly rebounded after the short positions were taken, and the subsequent signals to reverse position did not occur soon enough to avoid significant losses. Nevertheless, at one Filter 2 threshold (0.50%/1.00%), five of the six contracts, including the contract expiring in December 1987, were



profitable. (No trades were generated for the July 1985 contract.) At this threshold, losses on the two trades for the December 1987 contract were more than offset by gains on other trades. Total profits were \$7,654, the highest of either filter and any threshold percentage.

Table 3 displays selected performance measures for the simulated trading in copper futures using Filter 2 and the 0.50%/1.00% threshold. The largest gain (\$9,450) and the largest loss (\$4,100) for individual trades both occurred in the December 1987 contract. Also shown in Table 3 are figures for the maximum equity retracement for each of the six contracts. Maximum equity retracement refers to the greatest reduction in initial equity experienced from both

realized and unrealized losses once the first trade is made on a contract.

**Table 3. SELECTED PERFORMANCE MEASURES
FOR SIMULATED COPPER FUTURES TRADING
Filter 2: Initial/Reversal Threshold=.50%/1.00%**

Contract	Maximum Gain on a Trade	Maximum Loss on a Trade	Maximum Equity Retracement
January 1982	\$2,075	N.A.	\$1,088
March 1983	\$1,400	\$1,000	\$1,425
May 1984	\$ 850	N.A.	\$ 950
July 1985	N.A.	N.A.	N.A.
September 1986	\$ 238	N.A.	\$ 73
December 1987	\$9,450	\$4,100	\$2,363

N.A.=Not Applicable

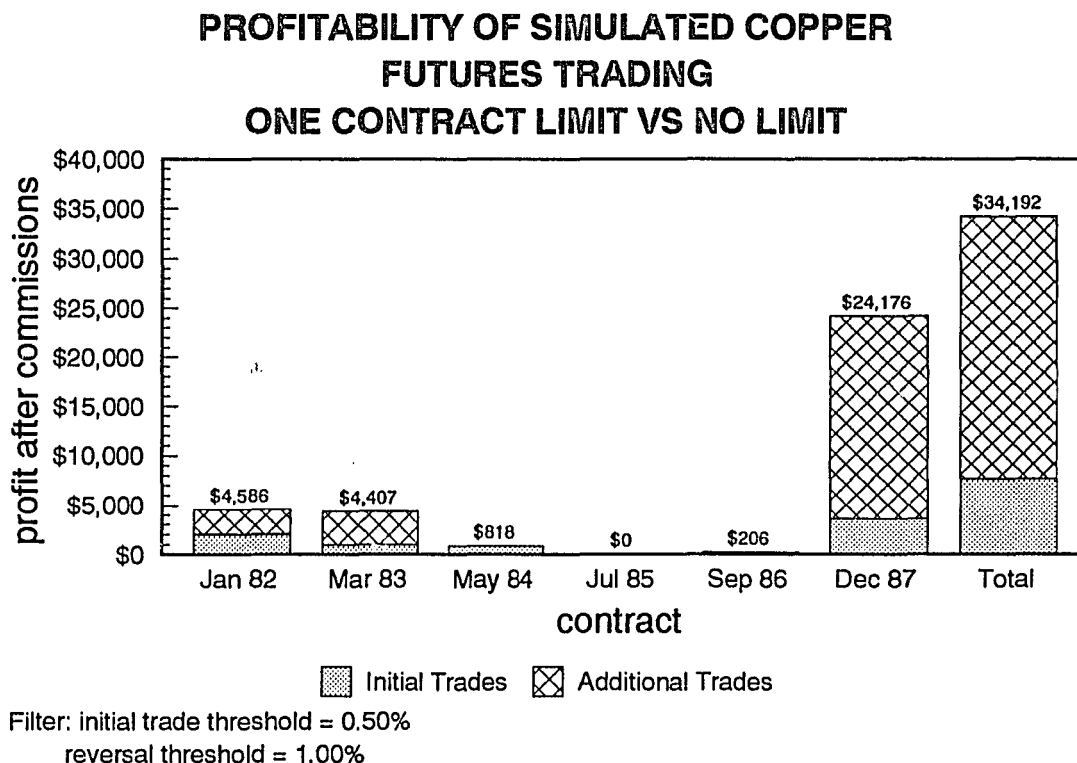
Since the realized and unrealized losses determine how much additional money a trader is required to deposit in the margin account, the maximum equity retracement plus the initial margin are an indication of the amount of funds required to trade the system. The initial margin is a financial guarantee, in the form of a deposit made by traders to a margin account, which ensures that the obligations of the futures contract will be fulfilled (CBOT, 1989). The size of the initial margin depends upon price volatility, but, to put it into perspective, the initial margin for trading copper futures contracts on COMEX in January 1990 was \$2,200 (Lind-Waldock, 1990). Thus, a relatively small amount of capital can control the full value of the futures

contract. In the case of copper, the value of the futures contract would be \$15,000, assuming a price of just \$.60 per pound. The maximum equity retracement for the five copper futures contracts for which simulated trades were recorded ranged from \$73 to \$2,363, so adding an initial margin of, say, \$2,200 shows that the total funds required to trade the system varied from \$2,273 to \$4,563, depending upon the contract. Comparing these figures with the profits for each contract (see Table 4, Initial Trades column) offers some idea of the return on investment for the 6-month simulated trading period.

The effects of relaxing the position limit of one contract were then examined, again using Filter 2 with an initial trade threshold of 0.50%. Thus, whenever the trader was long (short) and the 0.50% threshold was met or exceeded, another contract would be bought (sold). As indicated in Figure 16 and Table 4, this substantially increased the profits for three contracts, while no additional trades were generated for the others. Total profits for the six contracts rose from \$7,654 for the one contract position limit to \$34,192 when there was no limit on the number of contracts that could be held at one time. The number of trades increased by 16, 13 of which were profitable.

The system of trading copper futures contracts based on state space forecasting of futures prices shared many of the

Figure 16



characteristics of the trend-following strategies described in Chapter One. The highest level of profits was generated when the price series was increasing (December 1987 contract) or decreasing (January 1982 contract) fairly continuously over the entire period of the simulated trading. Profits were less when the price series was moving in a horizontal trading range or when prices were changing direction frequently. Unprofitable trades occasionally resulted from a short-term reversal in the overall trend of prices. Also, profits were foregone or losses incurred when the behavior of the price series changed radically, as it took a period of time for the model to respond to the changes.

**Table 4. PROFITABILITY OF SIMULATED
COPPER FUTURES TRADING
ONE CONTRACT LIMIT VS NO LIMIT
Filter 2: Initial/Reversal Threshold=.50%/1.00%**

Contract	Initial Trades	Additional Trades	Total
January 1982	\$ 2,043	\$ 2,543	\$ 4,586
March 1983	997	3,410	4,407
May 1984	818	0	818
July 1985	0	0	0
September 1986	206	0	206
December 1987	3,590	20,586	24,176
Total	\$ 7,654	\$26,538	\$34,192

3.3 Efficiency of the Copper Futures Market

The results of the simulated trading call into question the efficiency of the COMEX copper futures market. The trading strategy which was developed was based on state space forecasts of copper futures prices and the use of simple filters to generate trading signals. Multivariate state space models were employed, so the test of market efficiency was of the semistrong variety. With Filter 2 and an initial trade/reversal threshold of 0.50%/1.00%, five of the six contracts were profitable while no trading signals were generated for the other contract. A high proportion of the individual trades were also profitable.

Do the results of the simulated trading constitute conclusive evidence that the copper futures market is

inefficient? Market efficiency tests which have been conducted over the years have not been consistently applied, and criteria for making the efficiency determination are not always well-defined. Some have interpreted the mere presence of serial correlation in a price series as sufficient evidence to reject the efficient markets hypothesis, while others have based their efficiency determination on whether or not profitable trading rules can be developed.

In a discussion of Fama's article, Schwartz raises questions about Fama's conclusions that the capital market is basically efficient, and he points out the need for further clarification of several issues, some of which are relevant to this research. He indicates that a determination that a market is efficient can be reached only after all possible tests have been conducted, and there is always the potential for the development of a new method for analyzing historical data. Should the market, therefore, be considered less efficient if some traders, through the application of more advanced techniques, possess knowledge of certain relationships in the historical data or if no traders have this knowledge?

Similarly, although the rate of speed at which investors obtain and respond to new information is not explicitly treated in Fama's definition of market efficiency, any market advantage gained by the consistent, more rapid acquisition of

information would constitute, according to Schwartz, a transitory monopoly position which would probably be grounds for a determination that the market was not efficient. It would seem that a transitory monopoly position would also be conferred by the use of techniques that are better able to exploit available information and generate more accurate forecasts of future prices. Although many of these issues still appear to be unresolved, the consistent profits that were earned across a variety of time periods and economic conditions through the application of the state space forecasting approach to futures trading certainly suggest that, in the context of the contracts that were analyzed and the technique that was applied, the COMEX copper futures market may be inefficient in the semistrong sense. Because the addition of other variables to the state space models of copper futures prices did not make a great difference in the R^2 , the copper futures market may not be weak form efficient either.

3.4 State Space Models of Gold Futures Prices

As with copper, the state space models of gold futures prices were predominately of order 1, accounting for 97 percent of the total. Again, no models of order 3 or more were selected. To achieve acceptable residual statistics, seasonal models were required 18 percent of the time.

About 92 percent of the models contained one variable

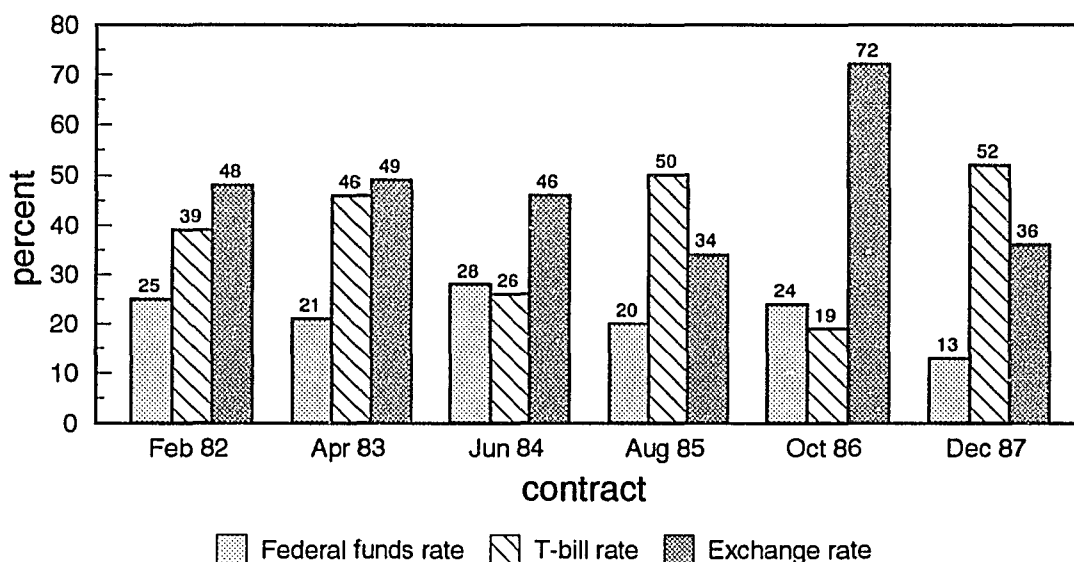
other than the gold futures price, and the remaining models were comprised of two variables. The R^2 was similar for models having different combinations of variables. There was a greater spread in the R^2 for the state space models of gold futures prices than for copper, as the range was 0.24 to 0.95.

The exchange rate was the variable appearing most frequently in the state space models of gold futures prices, and the dominance was most pronounced for the October 1986 contract (Figure 17). A substantial decrease in the trade-weighted value of the U.S. dollar was registered in 1986, and gold prices made a significant run up over the last four months or so of the life of the October 1986 contract. The role of the exchange rate in explaining variations in the price of gold confirms the results of other studies (e.g., Koutsoyiannis, 1983, and Newcomb and Tsuji, 1990).

Overall, the yield on Treasury bills was not as significant as the exchange rate in the models. In addition to the greater degree of market globalization which has caused exchange rate effects to, at times, overwhelm Treasury bill rates in importance, another possible explanation is that the capital gains which may be realized by holding gold can exceed the interest income foregone from other assets (Koutsoyiannis, 1983). Also, the ability to sort out the individual effects of interest rates and exchange rates on

Figure 17

PERCENT OF TIME VARIABLES APPEARED IN THE STATE SPACE MODEL OF GOLD FUTURES PRICES



gold prices is hampered in a single equation model, because, according to capital asset pricing theory, all these variables would be highly interrelated.

The federal funds rate appeared least frequently in the state space models of gold futures prices, ranking last for 4 of the 6 contracts.

3.5 Simulated Trading in Gold Futures Contracts

Total trades and the number of profitable trades for the simulated trading in gold futures contracts are shown in Table 5. For Filter 1, profitable trades account for roughly 50 percent of the total, while an even greater rate of

profitability is achieved at the higher threshold percentages for Filter 2. More trading activity occurred in the simulated trading of gold futures than for copper futures, possibly a function of fewer periods when the price series was approximating a random walk.

From the standpoint of dollar profits, both filters performed favorably (Figure 18). Filter 1 was superior to Filter 2 at the lower thresholds, but Filter 2 had a more pronounced advantage at the higher threshold percentages. As was true with copper, the greatest profits, \$21,670 in this case, resulted from the application of Filter 2 with an initial trade threshold of 0.50%. Trading in all six contracts was profitable for this Filter 2 threshold with profits for the February 1982 contract alone exceeding \$15,000. The maximum gain for an individual trade in the February 1982 contract was \$10,610, while maximum gains for the other contracts ranged from approximately \$1,000 to \$2,500 (Table 6). The April 1983 contract was the only one where any individual trades were unprofitable, and the largest loss on a trade was \$2,040. The maximum equity retracement for the six gold futures contracts ranged from \$0 (February 1982) to \$9,980 (April 1983). The initial margin for gold futures trading on COMEX was \$1,700 in January 1990 (Lind-Waldock, 1990), a small fraction of the total value of the futures contract. A gold price of \$400 per troy ounce

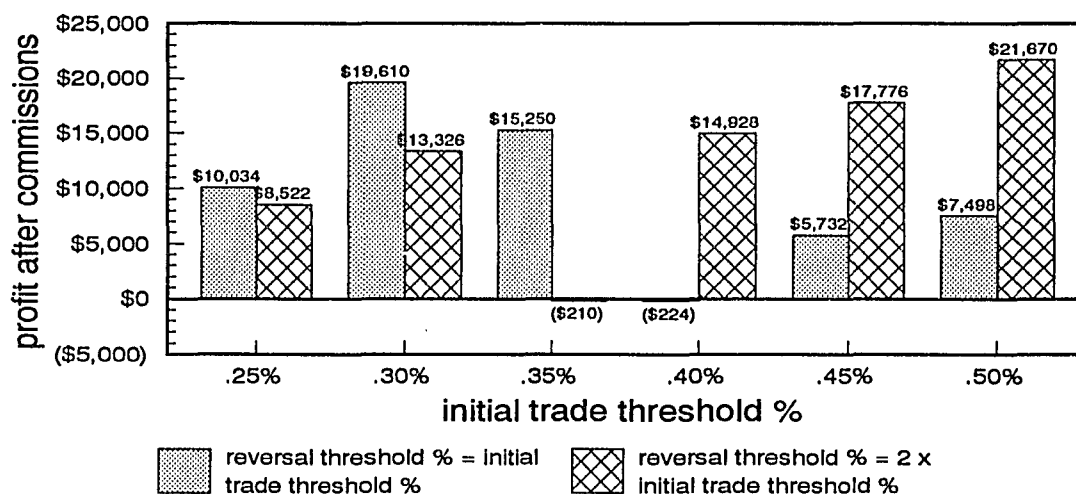
would, for example, make the total value of the contract equal to \$40,000. As with copper, comparing the profits for each contract (Table 7, Initial Trades column) with the sum

Table 5. TOTAL NUMBER OF TRADES AND THE NUMBER OF PROFITABLE TRADES (IN PARENTHESES) FOR SIMULATED GOLD FUTURES TRADING

Filter: Initial %/ Reversal %	Contract						
	Feb 1982	Apr 1983	Jun 1984	Aug 1985	Oct 1986	Dec 1987	Total
Filter 1 .25%/.25%	28 (14)	35 (19)	8 (5)	6 (2)	10 (5)	6 (3)	93 (48)
.30%/.30%	27 (13)	31 (16)	8 (5)	5 (2)	5 (3)	4 (2)	80 (41)
.35%/.35%	23 (12)	29 (13)	6 (4)	4 (2)	5 (3)	3 (2)	70 (36)
.40%/.40%	21 (11)	21 (7)	5 (3)	2 (1)	5 (3)	3 (2)	57 (27)
.45%/.45%	18 (10)	17 (5)	5 (3)	1 (1)	5 (4)	3 (2)	49 (25)
.50%/.50%	16 (10)	13 (3)	5 (2)	1 (1)	3 (2)	3 (2)	41 (20)
Filter 2 .25%/.50%	17 (10)	13 (3)	6 (3)	1 (1)	3 (2)	4 (2)	44 (21)
.30%/.60%	12 (7)	9 (3)	6 (4)	1 (1)	3 (2)	1 (0)	32 (17)
.35%/.70%	9 (6)	8 (2)	4 (3)	1 (0)	2 (2)	1 (1)	25 (14)
.40%/.80%	6 (4)	8 (2)	3 (2)	1 (0)	2 (2)	1 (1)	21 (11)
.45%/.90%	3 (3)	4 (1)	1 (1)	1 (1)	2 (2)	1 (1)	12 (9)
.50%/1.0%	3 (3)	3 (1)	1 (1)	1 (1)	1 (1)	1 (1)	10 (8)

Figure 18

TOTAL PROFITS FOR ALL GOLD FUTURES CONTRACTS USING TWO FILTERS



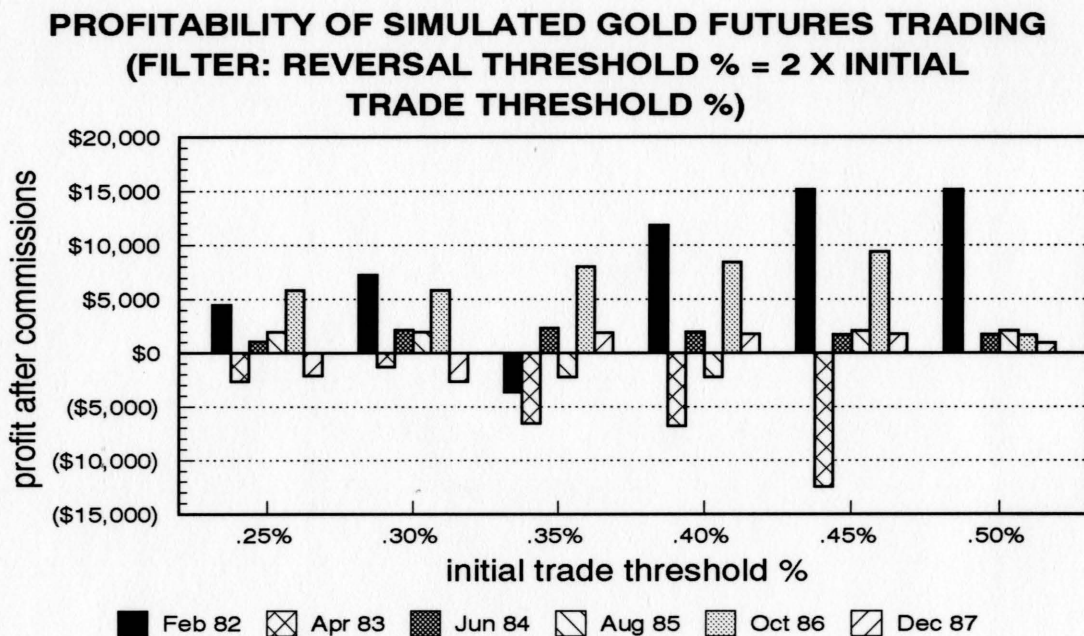
**Table 6. SELECTED PERFORMANCE MEASURES
FOR SIMULATED GOLD FUTURES TRADING**
Filter 2: Initial/Reversal Threshold=.50%/1.00%

Contract	Maximum Gain on a Trade	Maximum Loss on a Trade	Maximum Equity Retracement
February 1982	\$10,610	N.A.	0
April 1983	\$ 2,460	\$2,040	\$9,980
June 1984	\$ 1,740	N.A.	\$2,620
August 1985	\$ 2,150	N.A.	\$ 810
October 1986	\$ 1,730	N.A.	\$1,220
December 1987	\$ 980	N.A.	\$1,710

N.A.=Not Applicable

of the initial margin and the maximum equity retracement (Table 6) gives an indication of the return on investment.

Using Filter 2 with a threshold of 0.50%, the impacts of



allowing a position of greater than one contract were analyzed. The results were similar to those of copper with total profits significantly increased by relaxing the position limit. Profits rose for four of the individual contracts, remained the same for one, and decreased for one. For all contracts, profits jumped from \$21,670 to \$98,146. The removal of the position limit caused 27 additional trades to be made with 18 of these profitable.

Similar to copper, the state space forecasting-based system of trading gold futures achieved the greatest profitability when prices were trending upward or downward in a relatively continuous fashion. The February 1982 contract using Filter 2 and an initial trade threshold of 0.50% is an

**Table 7. PROFITABILITY OF SIMULATED
GOLD FUTURES TRADING
ONE CONTRACT LIMIT VS NO LIMIT
Filter 2: Initial/Reversal Threshold=.50%/1.00%**

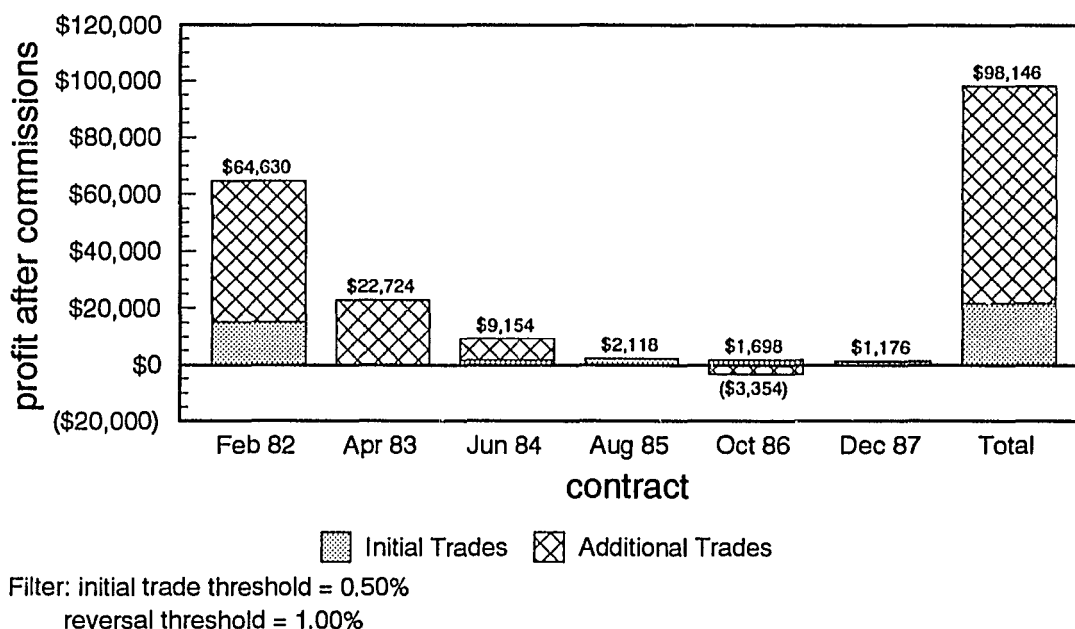
Contract	Initial Trades	Additional Trades	Total
February 1982	\$ 15,154	\$ 49,476	\$ 64,630
April 1983	44	22,680	22,724
June 1984	1,708	7,446	9,154
August 1985	2,118	0	2,118
October 1986	1,698	(3,354)	(1,656)
December 1987	948	228	1,176
Total	\$ 21,670	\$ 76,476	\$ 98,146

example of the success of the system under these conditions. One trade alone yielded more than \$10,000 in profits, as a *sell* signal was triggered early in the simulated trading period and the position was maintained as prices continued to fall until the expiration of the contract. Being able to increase the position by removing the one contract limit created an additional \$49,000 in profits for the February 1982 contract.

With 8 of 10 trades profitable using Filter 2, an initial trade threshold of 0.50%, and a position limit of one contract, the most notable deficiency of the state space forecasting system of trading gold futures contracts was that there were trades where profits could have been increased by earlier entry or exit from a position. The trading strategy again seemed to be effective at avoiding the generation of

Figure 20

PROFITABILITY OF SIMULATED GOLD FUTURES TRADING ONE CONTRACT LIMIT VS NO LIMIT



trading signals early in the simulated trading period, if prices were moving in no discernible pattern.

3.6 Efficiency of the Gold Futures Market

The results from the application of the state space forecasting approach to trading gold futures contracts suggest that the COMEX gold futures market may be semistrong inefficient. In terms of the total profits for all gold futures contracts traded in the simulation, a favorable outcome was achieved for almost every threshold level that was examined for each of two different filters. At the 0.50%/1.00% initial trade/reversal threshold for Filter 2,

trading was profitable for all six of the contracts. As noted above, little difference was noted in the coefficient of determination (R^2) as variables were added to the state space models of gold futures prices. Thus, similar trading results may have been achieved with univariate state space models, in which case the COMEX gold futures market would be considered weak form inefficient also.

CHAPTER FOUR

SUMMARY AND CONCLUSIONS

4.1 Summary

This research evaluated a system for trading futures contracts based upon state space forecasts of futures prices. Trading strategies were tested using copper and gold futures contracts traded on COMEX. For each commodity, simulated trading was conducted on six different contracts with the expiration dates for those contracts ranging from 1982-1987. The simulated trading was confined to the last six months of the life of the contract to insure adequate trading volume.

State space models of copper and gold futures prices were developed with consideration given to variables which could, on the basis of economic theory, influence futures prices. The models were evaluated weekly to ascertain whether changes should be made in the variables included in the models, and model parameters were reestimated daily. State space forecasts of the next day's settlement price were then made.

A trade was signalled whenever the forecast percentage change in the futures price met or exceeded a certain threshold level. Two different filters were examined: one where the threshold for a reversal of position was the same as for the initial trade in the simulation period (Filter 1) and another which required that the forecast percentage

change in prices for a reversal be twice that for the initial trade (Filter 2). Several different threshold percentages were evaluated for each filter.

For the simulated trading in copper futures contracts, the best performance was achieved with Filter 2 and an initial trade threshold of 0.50%. Of the five contracts for which simulated trades were made, no losses were incurred and profits totalled \$7,654. Removing the one contract position limit increased profits to \$34,192.

The results of the simulated trading in gold futures were also promising. As with copper, the highest profits were realized with the application of Filter 2 and the initial trade threshold of 0.50%. With a position constraint of one contract, trading in all six contracts was profitable using that Filter 2 threshold. Total profits were \$21,670. With no limit on the number of contracts which could be held at one time, profits rose to \$98,146. For both copper and gold futures, the system of trading based upon the state space forecasts of futures prices performed best when prices were trending upward or downward fairly continuously.

4.2 Conclusions

The research which has been conducted supports the hypothesis that a profitable system for trading commodity futures contracts can be developed using the state space forecasting approach. The trading strategy was evaluated for

a nonspeculative commodity (copper), as well as for a speculative asset (gold). The time period over which the simulated trading was performed covered widely varying economic conditions and a multitude of price patterns. Through the use of the state space forecasts of futures prices and the application of a relatively simple filter to signal a trade, consistent and, sometimes, significant profits were generated.

Issues relating to the definition of efficiency and the evidence that is required to determine whether a market is efficient or inefficient remain unresolved more than 20 years after Fama's work was published. The favorable results which were achieved in the simulated trading of copper and gold futures contracts suggest, however, that, within the scope of the contracts which were evaluated and the technique that was applied, the copper and gold futures markets may be inefficient. Since multivariate state space models were used to forecast copper and gold futures prices, the markets would be considered inefficient in the semistrong sense. Although weak form tests of efficiency were not performed, the fact that most of the explanatory power of the models originated from the lagged value of the futures price and the error terms is an indication that the copper and gold futures markets may also fail the weak form test of efficiency.

In general, statistically-based price forecasting

methods have received little attention in discussions of the various systems for trading in futures markets. The state space forecasting approach has, however, been shown to be a viable futures trading technique holding a number of advantages over other trading methods. Among these advantages are the ability to incorporate economic information into the model structure, the straightforward process for identifying and estimating the model, and the avoidance of much of the subjectivity inherent in the other techniques.

4.3 Future Research

The results of the study suggest several areas where additional research might be beneficial. For example, it was assumed that when a trading signal was generated, the trade was made at the next day's closing price. To explore the potential for greater profits, prices other than the next day's closing price could be used (e.g., the opening price) or criteria established such that the trade would be executed the following day when prices meet certain conditions.

The research evaluated a system for trading futures contracts based on state space forecasts of copper and gold futures prices. The price relationships among precious metals over different time periods could be analyzed by incorporating silver and platinum prices into the state space models of gold futures prices. Expanding the analysis to

include different types of futures contracts, such as those for financial assets or other commodities, also warrants further research.

The time interval for the data set used in testing the viability of the state space forecasting approach to futures trading could be adjusted. The trading system which was examined used daily data, but it would be informative to reduce the time interval to a shorter period. For example, state space forecasts could be made using data from hourly or 15-minute intervals or even from individual transactions. Information for variables other than the futures price may not be available that frequently, but this is not viewed as a major problem due to the relatively small impact on the coefficient of determination (R^2) observed for different combinations of variables.

Finally, *Forecast Master Plus* provides two options for state space modelling. One option treats all variables but the first as exogenous, whereas for the other option, all variables are considered endogenous. This research employed the latter option. Treating variables other than the futures price as exogenous would require the construction of individual state space models and forecasts for the other variables. Although this would involve more effort, the added modelling flexibility could result in improved forecasts and, hence, increased profits.

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