A Switching Analysis of United States Monetary Policy

by

Gary L. Shelley

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APPROVED:

Yannis Ioannides, Chairman

Rick Ashley, Chairman

Richard Cothren

Bill Smith

Catherine Eckel

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Committee Chairman: Yannis Ioannides

Department of Economics

(ABSTRACT)

This dissertation presents an empirical analysis of United States monetary policy over the period ranging from January 1973 to December 1985. Switching regressions are introduced as a method of allowing for discrete shifts in the coefficients of reduced form money supply equations. Two switching models are presented. The first is a monetary policy reaction function using a switching mechanism developed by Goldfeld and Quandt. In this first model, the probablility that a particular set of coefficients, or monetary rule, was in place in each sample month is determined by the level of a set of important economic aggregates. The second specification is a time series model in which M-1 money may follow one of two possible autoregressive processes in any given period. The particular process followed in each period is modeled as the outcome of a first order Markov process. Maximum likelihood estimates of each model are presented and interpreted. The results indicate that there were two periods of substantial monetary instability during this sample period.

The first period approximately begins in April 1973 and ends in February 1975. The second period corresponds closely to the set of months between the Fed's October 1979 and October 1982 changes in operating procedure. Results from the Goldfeld-Quandt model also show that the levels of four macroeconomic series, the interest rate, the inflation rate, the unemployment rate, and the trade weighted value of the dollar, may be used as indicators of the monetary rule being employed by the Federal Reserve.

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CHAPTER I

INTRODUCTION

The purpose of this dissertation is to extend the empirical literature on United States monetary policy by introducing the use of switching regressions as an improvement over previous ways of allowing for discrete changes in the parameters of reduced form money supply equations. Much of the previous empirical work in this area may be separated into two broad categories, time series ARIMA models, and monetary policy reaction functions. A policy reaction function is simply a reduced form equation showing how the Federal Reserve adjusts the value of its policy instrument to changes in important series such as unemployment and inflation rates. This study will present a switching model of a reaction function using the method originated by Goldfeld and Quandt (1973) as well as a time series model using the switching mechanism described by Hamilton (1988). The policy instrument or dependent variable specified in both models is the growth rate of M-1 money. It will be shown that these models avoid the conceptual and statistical problems associated with earlier approaches. It also will be demonstrated that the reaction function with Goldfeld-Quandt switching can be derived from a variety of theoretical models of the policy behavior of the Federal Reserve. As will be described below, both models presented here have passed a wide variety of statistical tests. Further, it will be shown that the results obtained from these models are consistent with previous descriptions of the Fed's policy actions during this sample period. Finally, it will be shown that the results are consistent with many of the theoretical results found in the rational expectations literature on monetary policy.

Given the potential impact of changes in the money supply on the economy, it is hardly surprising that considerable empirical research has been conducted concerning the behavior of this series. Most economists would agree that the growth rate of the money supply plays a significant role in determining the time paths of nominal variables such as the inflation rate, interest rates, and exchange rates. A proper analysis of past money growth then is needed in order to understand the historical behavior of these series. The importance of current and future movements in these variables to private economic agents also should be noted. For example, an unexpected change in interest rates or exchange rates can greatly affect a given year's profit for many firms. Therefore, any additional information regarding the parameters describing money growth which can be used to form better projections of the future paths of these series can be quite valuable.

Unfortunately, the relationship between money and real economic variables, such as real output and employment, remains controversial. However, one of the most basic results of the literature on rational expectations, that sudden unexpected changes in the money supply can have a significant impact on real variables, seems to have been fairly widely accepted in the profession. It also is widely accepted that such unanticipated changes in money are most likely to occur when there is some change in the parameters of the money growth process. These shifts in parameters will be referred to as changes in monetary regimes. An analysis of the historical behavior of monetary growth which includes identification of sudden changes in monetary regimes then also can lead to an improved understanding of the historical behavior of real variables.

One of the most important goals of monetary research is to evaluate the effectiveness of the Federal Reserve's past monetary policy and to recommend future improvements. This procedure must be based on a reasonably complete and reliable description of the historical behavior of the money series. One needs to know what monetary parameters (or rules) the Fed has used as well as when these rules were in place. For example, it is common to point to the Fed's Oct. 1979 change in operating procedures as a factor in causing (or at least in contributing to) the twin recessions experienced between 1979 and 1983. It is very important in evaluating the Fed's performance during this period to know if the announced change in operating procedures indeed was accompanied by some shift in monetary parameters. If evidence of a change in monetary regimes can be established, then it is possible that this lead to an unanticipated change in the money supply which then effected the behavior of real output. Also, if a change in monetary regimes did occur, then it is necessary to establish the timing of the shift before even the most basic causality argument can be made.

Finally, an empirical analysis of money is important because money supply equations enter into a wide variety of economic models. Both the type of results obtained from these models and the degree of confidence that should be placed in them may depend critically on the specification used for the money equation. For example, tests for the neutrality of money require the separation of the money series into anticipated and unanticipated components (see Mishkin 1983). This separation depends on the specification of the money supply equation. Misspecifying the money equation by failing to allow for changes in monetary regimes can greatly affect this separation and the results of the test.

Most early empirical work dealing with the historical behavior of the money supply was based on the assumption that both the reduced form coefficients of the money equation and the variance of the error (or innovation) process are constant. The main advantages of these models (either time series or reaction function) is the simplicity of the statistical theory behind them and the ease with which they can be estimated. However, given events such as the October 1979 change in the Fed's operating procedure, many researchers have begun to recognize that some method of allowing for changes in monetary parameters may be necessary. Unfortunately, most of the methods of allowing for structural shifts used to date suffer from problems which make both the resulting estimates and the conclusions drawn from them unreliable. The second chapter of this work discusses some of these methods and their problems. These methods then are contrasted with the switching regression approach to parameter changes.

The rest of this dissertation is organized as follows. Chapter 3 demonstrates how several existing theories of Federal Reserve behavior lead to switching in money rules that can be captured in a single model. Chapter 4 puts this theoretical model into a form which can be estimated using the Goldfeld-Quandt method. Chapter 5 presents both empirical estimates and statistical tests of the model. The results are interpreted and compared to previous descriptions of Fed behavior during this period in Chapter 6. Chapter 7 contains the time series switching model. A comparison of the results of the two switching models together with some concluding remarks is found in Chapter 8.

CHAPTER II

LITERATURE REVIEW

Several methods of specifying reduced form money supply equations have been used to allow for the possibility of changes in parameters. This chapter will survey some of the methods that have appeared in the empirical literature on monetary policy reaction functions. It will be shown that several problems associated with these earlier methods can be avoided by using the switching regression approach to estimation.

Papers by Froyen (1974) and Potts and Luckett (1978) tested the theory that changes in presidential administrations affect the Fed's conduct of monetary policy. In both papers, the test procedure was to divide the data set into subsamples corresponding to different administrations and then to estimate separate reaction functions for each subperiod. It was found that the resulting estimated policy rules indeed were different. These results do indicate that the Fed may make changes in its policy rule. However, Presidential influence is the only determinant of rule change allowed for in in these papers. Further, the data is divided into subsamples prior to estimation, so the behavior of the money series is given no weight in determining the dates of monetary rule changes. Therefore, it is quite possible that these models are misspecified. Significant differences in monetary coefficients across presidential administrations could be found even if the adjustments to the Fed's money rule occurred several periods before or after the changes in administrations.

McNees (1986) used a reduced form federal funds rate equation to determine whether the Fed bases its policy on realizations or on expectations of important series. It was theorized that the Fed placed a greater importance on money growth in the period between the Oct. 1979 and the Oct. 1982 changes in operating procedures. A dummy variable was created with a value of one for this period and a value of zero at all other times. Lagged money growth entered the equation with a fixed coefficient as well as with a second coefficient multiplied by the dummy variable. It was found that both realizations and expectations of series are important to the Fed. More importantly for this paper, the dummy variable was found to be significant. This indicates that the Fed may have been following a different policy rule over the 1979-1982 period.

Unfortunately, the estimation method used by McNees suffers from two severe weaknesses. First, the coefficient on lagged money growth was the only one allowed to vary; therefore, the untested restriction that all other coefficients remained constant was imposed. This problem can be solved simply by using the same method to allow for changes in all the coefficients. Secondly, the method used by McNees requires that the dummy variable and the resulting timing of regime changes be determined prior to estimation. As was discussed above, this can lead to misspecification of the model. It is quite possible that McNees' dummy variable would be significant even if the regime changes actually occurred several periods before or after the Oct. 1979 and Oct. 1982 dates specified. There are special circumstances in which this problem also can be addressed fairly easily. If the Fed actually did shift to a special rule for only one subperiod (for example between Oct. 1979 and Oct. 1982) then a researcher simply can experiment with the specification of the dummy series defining this period. One can run a set of regressions with different starting and ending dates for the special rule and choose the specification yielding the best fit. However, consider the difficulties involved if both rules were used more than once or if more than two rules were used. In either case, one would be faced with a tremendous number of possible specifications to choose from.

As a final example, consider the work by Barth, Sickles and Wiest (1982). They examined the possibility that the coefficient on a particular explanatory variable may vary with the level of that series. For example, suppose that the lagged rate of inflation is an independent variable entering the Fed's reaction function. Their idea is that the Fed's response to a one point increase in the inflation rate may be different when inflation is at two percent than when it is at ten percent. In other words, the reaction function may be nonlinear. Two sources of nonlinearity are allowed for. First, they divided their data into three subsamples based on whether the inflation rate was at a low, medium, or high level in each period. Separate monetary rules then were estimated for each subsample. This allows the coefficients to vary as the level of the series changes.

Secondly, squared and cubed values of the inflation series enter the regressions to allow for nonlinearity in variables. A cubic spline method was used to assure that the fitted rules joined at the boundaries of the subperiods. This procedure was repeated using the unemployment rate to divide the data into subsamples. In both cases it was found that coefficients did differ across subsamples, and that the three-rule spline estimates provided a better fit than fixed coefficient estimates. These results provide evidence that policy rules do vary and that series such as unemployment and inflation rates contain useful information for determining which rule is being followed by the Fed.

The estimation technique used by Barth, Sickles and Wiest is subject to three criticisms. First, the level of only one economic variable is used to divide the monetary series into regimes. However, the results of separate regressions presented in their paper indicate that at least two series, unemployment and inflation, should be used as indicators of the Fed's policy rule. Since relevant information is omitted, their estimates cannot be efficient. This problem can be avoided by using an index composed of several series as an indicator; however, the weights of such an index would have to be determined prior to estimation if the spline method is used. This would require exact prior information regarding the relative usefulness of different series for indicating the Fed's rule. A second criticism is that the researcher must decide what is a "low" or "high" level of the index (or series) prior to estimating the model. The separation of the data into subsamples then is somewhat arbitrary. Finally, as with all the methods described earlier, the behavior of the monetary series plays no part in determining when a particular money rule was being used by the Fed. The econometrician divides the money series into regimes without examining the behavior of the series itself.

Switching regressions provide a way of allowing for rule changes which avoids the problems associated with earlier methods. Consider first the Goldfeld-Quandt switching model used in this paper. It begins by assuming that a fixed number of monetary rules has been used by the Fed during the set of sample months. All the monetary parameters are allowed to vary across rules. Associated with each rule is an index which determines the probability that this rule was used in a particular sample month. Each index is composed of the same set of important aggregate series, the inflation rate, the unemployment rate, the six-month treasury bill rate, and the trade-weighted value of the dollar. The weights on the series in an index are parameters to be estimated simultaneously with the coefficients of the money rules. The estimation method sets the weights of the indexes such that a particular rule will have a high associated probability in those periods in which it best fits the observed money series. This means that the information contained in the aggregate variables entering the indexes is used together with the observed behavior of the money series to determine which rule the Fed was most likely following in each period.

The time series switching model also uses the information in the money series to determine when rule changes have occurred. This model allows for two different sets of parameters in an otherwise standard ARIMA representation of he M-1 money growth process. Again, all the monetary parameters are allowed to vary across rules. These two sets of parameters may be thought of as different states of money growth. The pattern of realization of the two states is summarized by a set of first order Markov probabilities. For example, if money growth was in state one last period, there is some probability that it will be in state one again this period (or that it will switch to the other state). The estimation algorithm developed by Hamilton combines these estimated transition probabilities with a measure of how well a particular period's actual money growth fits the estimated equation for each state. This determines the probability that money growth was in a particular state in a given period. This probability as well as the money parameters and the Markov transition probabilities all are determined together in a single estimation step. Again it the information contained in the money series helps select the monetary state or rule.

An additional benefit of using these switching models should be noted. Observations from different subperiods within the data sample may be pooled to estimate the coefficients of a given rule. This makes it possible to obtain more observations on a rule and more efficient estimates of its parameters. This also makes it possible to identify relatively short episodes in which a rule was used. For example, suppose that a particular rule (denote it rule one) was in place for six months during 1974 and for 18 months in the 1979-1980 period. Further suppose that there are eight parameters associated with rule one. Switching methods easily incorporate all the observations from both regimes into the estimates of the rule one parameters. Since there are eight parameters to be estimated but only six observations on the 1974 regime, it would not be possible to separately estimate this episode and statistically compare it to the rule used in the 1979-1980 regime.

CHAPTER III

A THEORETICAL SWITCHING MODEL OF THE FEDERAL RESERVE'S MONETARY POLICY REACTION FUNCTION

Most researchers would agree that policy analysis should be based on the assumption that the Fed is an optimizing agent. The Fed's policy rule then can be viewed as the solution to a problem in which some objective function is maximized subject to the constraints imposed by the structure of the economy. The Fed's objective could be defined in a mathematical model simply as the maximization of some function assigning regret to factors such as unemployment, inflation, or exchange rate volatility; however, there is little consensus regarding the "true" structure of the aggregate economic system. Therefore, the proper set of constraints to be imposed on the problem is unknown. This difficulty has been avoided by many applied researchers by simply estimating a reduced form reaction function. It then is assumed that the Fed's actual policy rule is based on some implicit model of the economy.

The reaction function specified in this paper is a reduced form money growth rate equation which allows for changes in policy regimes. As discussed above, it is assumed that the Fed's money supply rule is the unique solution to a constrained optimization problem. It follows from this assumption that regime changes occur because of switches in the parameters of the Fed's objective function and/or changes in its perception of the structure of the economy. If both the objective function and the set of structural constraints are constant, then the resulting money rule remains optimal. There is no reason for the Federal Reserve to change policy rules. However, a shift either in objectives or in the Fed's perception of the economic structure implies a different solution to the optimization problem and a new money rule. A model which allows for changes in monetary regimes then must examine both why the Fed would choose to alter its objective and how the Fed would come to recognize that a significant structural change has occurred.

First consider a situation in which the Fed may alter its objective function. For simplicity, assume that the Fed in each period must choose between two policy goals. The objective function then takes the form:

$$(1)\ \text{Min:}\quad R_t\left[\Psi_1 I_t + \Psi_2(1-I_t)\right]$$

where R_t is a row vector of endogenous variables the Fed is interested in influencing, Ψ_1 and Ψ_2 are column vectors (conformable with R_t) of parameters, and at least one element of Ψ_1 is not equal to the corresponding element of Ψ_2. I_t is a scalar indicator function taking a value of either zero or one. The vector R_t may contain squared values or cubed values of the endogenous variables. A switch in the value of I_t reflects a change in the relative importance the Fed places on the two policy goals. For example, suppose that R_t contains squares of the unemployment rate and the inflation rate. A switch in

I_t from one to zero changes the vector of weights placed on these variables from Ψ_1 to Ψ_2 and would cause the Fed to switch from one linear reduced form money rule to another.

Several existing descriptions of the Fed's policy behavior are consistent with an objective function such as the one shown in equation (1). First, suppose that the Fed is interested in keeping an economic variable (or set of variables), r_t, within some range of values bounded by a pair of tolerance limits. Any value of r_t falling within this range is equally acceptable to the Fed; however, any movement in r_t to a point outside the range increases the amount of regret imposed on the Fed. A movement in r_t across the tolerance limits then will result in a switch in I_t.

This type of switching in the objective function leads to a specific type of change in the coefficients of a reduced form money growth rule. A given change in r_t which leaves the series within the acceptable range will leave the level of regret felt by the Fed unaltered; therefore, no monetary response is required. In this case, a reduced form money rule will place a zero coefficient on the movement in r_t. However, if the same amount of change in r_t drives the variable outside the acceptable range this will impose positive regret on the Fed. The Fed will respond to this movement in the series and the reduced form money rule will place a nonzero coefficient on the change in r_t. The reduced form coefficient on a change in r_t then depends on the level of the r_t series. Further, the coefficient should be switching to and from a zero value as r_t crosses its tolerance limits. A good example of this type of behavior is the exchange rate policy described by Flood and Garber (1983). In their model, the Fed does not attempt to peg the exchange rate to a particular value; however, it does intervene in the foreign exchange market to keep the exchange rate within a range of values. If the Fed follows such an exchange rate policy, or if it treats some other economic series in this manner, then its objective function will resemble the one described in (1), and the the coefficients of the reduced form reaction function will exhibit the type of switching behavior just described.

Duesenberry (1983) describes a second possible cause for changes in the parameters of the Fed's objective function. Following World War II, the federal government assumed responsibility for conducting fiscal and monetary policies designed to promote macroeconomic goals such as price stability and low unemployment. This new role of government is embodied in legislation such as the Employment Act of 1946. Unfortunately, government policymakers may face tradeoffs between conflicting goals. For example, a restrictive monetary policy designed to reduce the rate of inflation may result in an increase in the unemployment rate. The selection of policies to implement then depends on the preferences of the policymakers. It is quite possible for the preferences of the fiscal authorities (the legislative and executive political branches of government) to conflict with those of the monetary authority (the Federal Reserve). This conflict could be caused by differences in the time horizons of the fiscal and monetary authorities. Members of the Board of Governors of the Federal Reserve have 14 year terms. It is quite possible that they may be more concerned with long term stability than with temporary movements in an economic variable such as the unemployment rate. However, an increase in the unemployment rate for even three months may be of great concern to a Congressmen involved in an election campaign.

The structure of the Federal Reserve is designed to minimize the influence of political factors on the conduct of monetary policy. The Federal Reserve System is self-financing and Board members serve 14 year terms. However, as Duesenberry notes, the Fed is not completely insulated from political pressure. If it is perceived as being completely unresponsive to the concerns of the fiscal authorities, it faces a number of potential penalties. For example, Congress could take action to reduce the independence of the Fed. It could require Congressional approval of Federal Reserve expenditures, or political officials such as the Secretary of the Treasury could be given voting membership on the Board of Governors (or on the Federal Open Market Committee). Legislation could be passed requiring the coordination of Fed monetary policy with Congressional (or executive) statements of fiscal policy objectives. Although it is very unlikely, it even is possible for Congress to amend the Federal Reserve Act and give the Treasury Department complete control of monetary policy. In summary, if the Fed wishes to insure the continuation of its present degree of power and independence, it cannot appear to be completely unresponsive to Congressional concerns.

If the Fed responds to the type of pressure described by Duesenberry, then it at times allows its own preferences regarding the conduct of monetary policy to be replaced by those of the fiscal authorities. In terms of equation (1), this would mean a switch in I_t from one to zero and an accompanying change in the parameter vector from Ψ_1 (reflecting the Fed's preferences) to Ψ_2 (capturing fiscal concerns). This is most likely to occur when an important economic aggregate such as the inflation rate or unemployment rate reaches a level high enough for the political forces to become concerned while Federal Reserve policy is perceived to be in conflict with that concern. For example, suppose that the Fed has decided that it is willing to tolerate an increase in the unemployment rate in return for lowering the rate of inflation. It then begins to follow a policy of restricting the rate of growth of M-1. As the unemployment rate rises to higher levels, the Fed is likely to feel increasing political pressure to relax its tight money rule and try to alleviate Congressional concerns about unemployment. The levels of important economic series may determine the probability that the Fed will bow to political pressure, adjust the parameters of its objective function, and change its money rule.

As was noted above, imposing a different set of constraints on the Fed's optimization problem results in a different set of parameters for its money rule. Therefore, a change in monetary regimes may occur because the Fed perceives a change in the economic structure. It seems reasonable that such a structural change will have some effect on endogenous economic variables. Therefore, a change in the behavior of the economic series monitored by the Fed may lead it to conclude that a strucural change has occurred. However, for the Fed to attribute a movement in a series to structural change, the move would probably have to be persistent and of significant magnitude. Small movements are a part of the natural motion of economic series and even large movements that are temporary may be treated simply as outliers. A prolonged significant shift in the levels of important economic series then may lead the Fed to conclude that a structural change has occurred and to change its money rule.

If anticipated money supply changes are neutral in affecting real variables then one of the constraints facing the Fed is the expectations of private agents. As was shown by Kydland and Prescott (1977), the Fed may face a time consistency problem. A rule that was optimal given the public's expectations at the time of its adoption may no longer be optimal if these expectations change. For example, suppose the Fed is considering a rule which would lead to rapid growth in the money supply. If private agents expect a low rate of money growth then the rule will result in a decrease in the unemployment rate and a relatively small increase in aggregate prices. The high money growth rule may be optimal and be adopted by the Fed. However, if after some time the public begins to anticipate the higher money growth rate, continuation of the rule will lead to higher inflation with little or no accompanying reduction in unemployment. The rule would become suboptimal and be dropped as soon as the Fed recognizes the change in expectations.

If monetary regime changes can be caused by changes in the Fed's perception of the public's expectations, then it becomes important to consider how the Fed forms its perception. The levels of important aggregate economic series may help provide the Fed with useful information. If the public anticipates high money growth then inflationary expectations will be high. It should be noted first that this is more likely to occur during times of high actual inflation. Secondly, the nominal interest rate is the sum of two components, an expected real rate of interest and an inflation premium. If nominal rates appear unusually high, this may be caused by expectations of high inflation. Finally if high inflation and high nominal interest rates are observed during a period when expected real interest rates should be low (possibly during recession) then the Fed may conclude that the public is expecting fast money growth and high inflation. The Fed's observation of changes in the levels of such series as the inflation rate, unemployment rate, and nominal interest rates then may cause it to change its money rule.

In summary, a change either in the parameters of the Fed's objective function or in the economic structure results in a switch in the coefficients of the Fed's reaction function. A reaction function which allows such a change in money rules is given by:

$$(2)\ M_t^S = D_t\left[X_t\gamma_1 + m_{1,t}\right] + (1-D_t)\left[X_t\gamma_2 + m_{2,t}\right];$$

where: M^S_t is the growth rate of the money supply at time t, D_t is a scalar indicator taking a value of either zero or one, X_t is a row vector of explanatory variables entering each money rule, γ_j is the column vector of parameters of rule j, and $m_{j,t}$ is the innovation to money in rule j at time t resulting from inexact control of the money supply by the Fed. A change by the Fed from the first money rule to the second corresponds to a switch in the value of D_t from one to zero.

In all the situations described above, the levels of important aggregate series contain information regarding the timing of changes in money rules. This was true regardless of whether the rule change was caused by a switch in objective parameters or a change in the Fed's perception of the economic structure. Suppose that these economic series are combined into an index, Z_t. The D_t indicator and its switching process then can be described by the following equations.

$$(3)\ D_t = \begin{cases} 0 & \text{if } Z_t \leq Z^* \\ 1 & \text{if } Z_t > Z^*; \end{cases}$$

$$(4)\ Z_t = R_t\alpha.$$

Equation (3) shows that the Fed's choice of the value of D_t is based on the relation of the index Z_t to some critical value Z^*. Equation (4) defines the Z_t index as a linear combination of a set of aggregate economic series contained in the row vector R_t. The weights of the index are given by a column vector α. A change in the level of the series in R_t can force the index Z_t through the critical value Z^*

causing a switch in D_t and the adoption of a new money rule. If the Fed is seeking only to keep some series within a tolerable range, then Z_t is made up of this series and Z^* is one of the tolerance limits. If the Fed is responding to political pressure, then Z_t is the series with which the fiscal authority is concerned, and Z^* is the point where the Fed is forced to respond to this concern. If a new rule is adopted as a result of a change in the Fed's perception of the structural constraints, then Z_t is the set of series the Fed is observing, and a movement past Z^* is one large enough to be attributed to structural change.

It should be noted that without estimates of the parameters of the Fed's objective function and the structural constraints, it is not possible to determine with any certainty why a regime change occurred. One cannot distinguish between the theoretical explanations described above using only reduced form estimates of the reaction function. For example, suppose that a regime change occurred when the unemployment rate reached a very high level. One cannot be sure if the Fed changed its money rule because Congress became concerned about the level of unemployment or because it interpreted the increase in unemployment as a signal of structural change.

Finally, it should be noted that switching in the parameters of linear money rule equations (as specified in equation (2)) could result if the Fed's actually is following some fixed coefficient nonlinear money rule. In this case, one would be simply estimating separate segments of the nonlinear function with the different linear equations. Unfortunately, this possibility is difficult to distinguish empirically from the previous explanations for parameter changes. If the Fed's true reaction function is nonlinear in the explanatory variables, then the linear estimates of different segments would correspond to different levels of these variables. Further, the index Z_t is likely to be a good set of instruments for these explanatory variables since Z_t is supposed to contain variables of interest to the Fed and because there is a high degree of correlation between aggregate economic series. Therefore, it is possible that a model with switching in linear money rules as described by equations (2)-(4) could be simply an approximation of some single nonlinear money rule.

CHAPTER IV

AN ECONOMETRIC SWITCHING MODEL OF THE REACTION FUNCTION

The major obstacle in estimating the reaction function derived above is that the D_t indicator series is a latent variable. The econometrician cannot perfectly recreate this series since both the Z_t index and its critical value Z^* are known only by the Fed. Even the exact composition of the R_t vector is unknown to the researcher. Therefore, it will not be possible to say with certainty which money rule was being used in each sample month. However, it is possible to assign a probability to the event that a particular rule was chosen by the Fed.

Consider the model described by equations (2)-(4) and for the moment assume that the Z_t index is observed for some series of months. The probability that Z_t is greater than the unknown boundary Z^* increases as one moves to larger values of the index. Therefore, as Z_t increases in size, the probability that the Fed was using the second money rule becomes greater. This can be summarized as:

$$(5)\quad M_t^S = \begin{cases} X_t\gamma_1 + m_{1,t} & \text{with probability } (1-\lambda_t) \\ X_t\gamma_2 + m_{2,t} & \text{with probability } \lambda_t; \end{cases}$$

$$(6)\quad \lambda_t = F(Z_t) = F(R_t\alpha);$$

where F( ) is some cumulative density function and all other variables are as defined earlier.

The reaction function given by equations (5) and (6) still is not in a form which can be estimated because the Z_t index is unobserved and the exact composition of the R_t vector is unknown. However, suppose that there exists some set of observable variables which can serve as reliable instruments for the series in R_t. Then a new index $\hat{Z}_t$ can be defined as:

$$(7)\quad \hat{Z}_t = N_t\beta,$$

where N_t is a row vector containing the set of instrumental variables, and β is a column vector of coefficients conformable with N_t. If the β coefficients are correctly chosen, $\hat{Z}_t$ should closely approximate Z_t. Therefore, equations (5) and (6) can be rewritten as:

$$(8)\quad M_t^S = \begin{cases} X_t\gamma_1 + m_{1,t} & \text{with probability } (1-\hat{\lambda}_t) \\ X_t\gamma_2 + m_{2,t} & \text{with probability } \hat{\lambda}_t; \end{cases}$$

$$(9)\quad \hat{\lambda}_t = F(\hat{Z}_t) = F(N_t\beta);$$

with $\hat{\lambda}_t$ being close in value to λ_t. The form of the reaction function given by equation (8) can be estimated. The dependent variable $M^S{}_t$ as well as the explanatory variables X_t and N_t are assumed to be observable.

The only remaining problem is the selection of the N_t vector of instruments. Four aggregate series will be used, the unemployment rate, the inflation rate, the rate of interest, and the trade weighted value of the dollar. Given the importance of these series, both the fiscal authority and the Fed are likely to be interested in their behavior. Fiscal concern with movements in these series are likely to be a source of political pressure on the Fed. It also is possible that the Fed simply attempts to keep their values within some tolerable range. Therefore, changes in the levels of these series are a potential cause of changes in the parameters of the Fed's objective function. Further, observation of movements in these series are likely to have a significant impact on the Fed's perception of the economic structure. Finally, given the high degree of correlation between aggregate series, these variables should be reliable instruments for any other series contained in R_t.

The policy reaction function given by equations (8) and (9) easily can be extended to allow for more than two money rules. Let the subscript j denote variables in the j'th money rule. Then (8) and (9) may be rewritten as:

$$(10)\quad M_t^S = X_t\gamma_j + m_{j,t} \qquad \text{with probability } \hat{\lambda}_{j,t};$$

$$(11)\quad \hat{\lambda}_{j,t} = F(N_t\beta_j).$$

One extra condition is needed:

$$(12)\quad \sum_{j=1}^{J} \hat{\lambda}_{j,t} = 1,$$

where there are J money rules. Equation (12) simply ensures that the probabilities sum to unity. Equation (10) is the form of the reaction function which will be estimated in this paper.

It should be noted that only lagged variables will be included in the X_t and N_t vectors to avoid the possibility of correlation between these series and the innovations $m_{j,t}$. It is well known that such correlation would lead to inconsistent estimates of the coefficients of the model. The selection of only lagged explanatory variables can be justified by pointing to the fact that most economic series are reported only after some lag; therefore, the current value of most series is not in the Fed's information set. One also could assume that the Fed chooses its money rule and conducts operations at the beginning of each period, prior to the realization of most time t variables.

The reaction function (10) can be estimated using a technique suggested in Goldfeld and Quandt (1973). This method is known as stochastic switching on the basis of other variables. Assuming that each $\{m_{j,t}\}$ process is mean zero and distributed iid normal, the money supply has the following probability density function (pdf) conditional on the selection by the Fed of rule j:

$$(13)\quad f(M_t^S|X_t, \text{ rule } j) = f_{j,t} = \frac{1}{\sqrt{2\pi}\,\sigma_j} \exp\left[-\frac{1}{2}\left[\frac{M_t^S - X_t\gamma_j}{\sigma_j}\right]^2\right]$$

where σ_j is the standard deviation of $m_{j,t}$. Equations (11) and (13) yield the pdf for M^S_t:

$$(14)\quad g(M_t^S|X_t) = \sum_{j=1}^{J} \hat{\lambda}_{j,t}\, f_{j,t}.$$

The cumulative density function used to determine $\hat{\lambda}_{j,t}$ is:

$$(15) \quad \hat{\lambda}_{j,t} = \frac{\exp(N_t \beta_j)}{\sum_{j=1}^{J} \exp(N_t \beta_j)} .$$

The logistic function (15) was chosen for its simplicity and close approximation to the normal cdf. As in the standard logit model, β_1 is normalized to a vector of zeros to identify the β_j coefficients. It should be noted that the model is underidentified in the sense that any one of the J money rules could be designated as j=1.

Given equations (13)-(15), the parameters of the reaction function can be estimated by the method of maximum likelihood. The log likelihood function is:

$$(16) \quad L = \sum_{t=1}^{T} \log\left[\sum_{j=1}^{J} \left[\frac{\hat{\lambda}_{j,t}}{\sqrt{2\pi}\,\sigma_j} \exp\left[-\frac{1}{2} \left(\frac{M_t^S - X_t \gamma_j}{\sigma_j} \right)^2 \right] \right] \right] ,$$

where there are T observations. This function is maximized with respect to γ_j, β_j, and σ_j for all $j \in \{1, 2, \ldots, J\}$. All estimates reported in this paper result from maximization of (16). The particular maximization algorithm used, BHHH, is discussed briefly in Appendix I.

The maximum likelihood method basically seeks to minimize the the sum of the squared residuals from each money rule multiplied by the weights $\hat{\lambda}_{j,t}$:

$$(17) \quad \text{Min:} \sum_{t=1}^{T} \sum_{j=1}^{J} \hat{\lambda}_{j,t} (m_{j,t})^2 .$$

Therefore, the β_j coefficients are chosen so that on average the rule resulting in the smallest squared residual is given the highest probability of occurring. The information contained in the variables composing N_t is used jointly with the realizations of the money series to determine which rule was most likely used in a given month.

Because $\hat{\lambda}_{j,t}$ determines the weight that a particular observation will be given in estimating the parameters (γ_j) of money rule j, this probability functions in a manner very similar to that of a Bayesian prior. The main difference is that $\hat{\lambda}_{j,t}$ is determined during, not prior to, estimation. Once estimates of the β_j and γ_j coefficients are obtained, it is possible to form a revised probability that a particular realization of the money series was generated by a given money rule. This procedure is very similar to the formation of a posterior probability in Bayesian analysis. The post-estimation probability for this model is given by:

$$(18) \quad \text{Postprob}_{j,t} = \frac{\hat{\lambda}_{j,t}\, f_{j,t}}{\sum_{j=1}^{4} \hat{\lambda}_{j,t}\, f_{j,t}},$$

where $f_{j,t}$ is given by equation (13). The information contained in the observed money series is incorporated directly into this probability through $f_{j,t}$ and indirectly by the series' influence on the estimates of the β_j coefficients. This is the probability used below to determine which money rule was most likely used at each sample date.

CHAPTER V

PARAMETER ESTIMATES AND STATISTICAL TESTS OF THE GOLDFELD-QUANDT MODEL

Results of this study are based on a monthly data set with observations ranging from January 1973 to December 1985. The number of possible policy rules was limited to four. As mentioned before, the policy instrument, or dependent variable, is log differenced M-1 money. The independent variables of each money rule (the elements of X_t) are a constant and one lag each of M-1, the six month T-bill rate, the consumer price index, the unemployment rate, the trade weighted value of the dollar, the Standard & Poor's stock index, and an index of industrial production. Each of these series is in log differenced form. Rule selection is assumed to be based on a constant, and one lag each of the six month T-bill rate, the inflation rate, the unemployment rate, and the trade weighted value of the dollar. These components of N_t are in levels. All results discussed in this section may be found in the set of tables in Appendix II.

The first question to be addressed is whether the fit of an estimated policy reaction function is significantly improved by allowing for the possibility of rule switching. This question may be answered by conducting a likelihood ratio test. The test statistic here is:

$$(19)\quad LR = -2[L_r - L_u] \sim \chi^2_{(k_1+k_2+1)} ,$$

where L_u is the unrestricted log likelihood obtained from a switching model with 2 possible money rules, and L_r is the restricted log likelihood obtained from a model allowing for only a single money rule. As discussed in Goldfeld and Quandt (1973), this statistic is approximated well by a χ^2 distribution with $(k_1 + k_2 + 1)$ degrees of freedom. Here k_1 and k_2 respectively are the dimensions of the γ_j and the β_j vectors. As reported in table 2, it was found that moving from a fixed coefficient to a two-rule model does lead to a significant improvement in the fit of the money equation. In fact the marginal significance level of the test statistic is less than 1%, indicating that the difference in the fit of the two models is quite large. Estimates of the fixed coefficient model are provided in table 6.

The next step is to determine if fit is significantly improved by increasing the number of money rules allowed for in the switching model. The test statistic is exactly the same here as in (19), where L_u is the log likelihood of the model allowing for J rules, and L_r is the log likelihood of the model allowing for only (J-1) rules. It was found that fit is significantly improved by moving both from a two-rule to a three-rule model and from a three-rule to a four rule model. In both instances the marginal significance level of the test statistic is less than 1%. The statistics for these tests are provided in table 2. Since it is superior in terms of fit to models allowing for fewer rules, only the results from the four-rule model are discussed in this paper. Estimates of the parameters of the four-rule model are presented in table 1.

As discussed above, the estimates of the γ_j and β_j coefficients are used to form a probability that a particular money rule was being used by the Fed in each of the sample periods. These "post-probabilities", derived from equation (18), are listed in table 7. Given these probabilities and the estimated coefficients of the money rules, a fitted value for the growth rate of money in each period can be obtained from:

$$(20)\quad \hat{M}^S_t = \sum_{j=1}^{4} \text{Postprob}_{j,t}\, \hat{M}^S_{j,t} \;;$$

where:

$$(21)\quad \hat{M}^S_{j,t} = X_t \hat{\gamma}_j .$$

The resulting residuals are given by:

$$(22)\quad \hat{m}^S_t = M^S_t - \hat{M}^S_t \;.$$

For a single-rule model these simply would be the OLS residuals.

These residuals can be used to make some interesting comparisons of the in-sample fit of the four-rule switching model of money growth to that of the standard single-rule model. The four-rule and OLS residuals are plotted in figures 14 and 15. Perhaps the simplest comparison of goodness of fit can be obtained by examining the root mean squared error (RMSE) of the two models, where:

$$(23)\ \text{MSE} = \frac{\sum_{t=1}^{T} [\hat{m}_t^s]^2}{T},$$

and RMSE equals the square root of the MSE. The RMSE is equal to .00275 for the four-rule model and .00424 for the single-rule model. Use of the switching model then leads to a 35% decrease in RMSE.

It also is possible to construct a quasi-R^2 for the four rule model of money growth which can be compared to the R^2 obtained from OLS estimates of the single-rule model. Use of the switching model leads to a quasi-R^2 of .6963, while only .2802 is obtained from OLS estimates. This again demonstrates the improvement in fit offered by the switching model. The term "quasi" is used here because the R^2 measure is based on the assumption that the dependent variable in a regression has a constant mean. When one allows for switching, it is possible for the mean money growth rate to vary across policy rules.

The estimated four-rule model next is subjected to a series of statistical tests. These tests are necessary to verify the assumptions upon which the econometric model and its results are based. The first assumption is that each of the X_j variables is important in explaining money supply movements. Standard t-tests of the significance of each coefficient in the γ_j vectors are conducted. The test statistics and their marginal significance levels are listed in the last two columns of table 1. Notice that each explanatory variable included in the X_j vector has a significant coefficient at the 5% level in at least one rule.

Similarly, a set of likelihood ratio tests was conducted to determine the overall explanatory power of each of the variables in N_t. Equation (19) again gives the form of the test statistic, where L_r now refers to the log likelihood of a model with one particular variable excluded from the N_t vector, and L_u refers to the log likelihood of the full model with the variable included. The test statistics for both the unemployment rate and the rate of inflation are significantly different from zero at the 1% level. These series do contain significant information concerning the Fed's choice of money rules. The test statistic for the trade weighted value of the dollar, however, has a marginal significance level of only approximately 14%. This indicates that the trade weighted value of the dollar is not as useful as the unemployment and inflation rates for identifying monetary regimes within this sample period. These tests are listed in the last three rows of Table 2. To date, a model excluding the interest rate from N_t has not been estimated successfully.

Recall that the log likelihood function (16) is based on the assumption that the $\{m_{j,t}\}$ processes are distributed iid normal. Therefore, the existence of serial correlation in the innovation processes would invalidate the estimation results. Notice that equations (20) to (22) imply that the residual series $\hat{m}_t$ can be written as:

$$(24)\quad \hat{m}_t^S = \sum_{j=1}^{4} \text{Postprob}_{j,t}\, \hat{m}_{j,t} \ ;$$

where:

$$(25)\quad \hat{m}_{j,t} = M_t^S - \hat{M}_{j,t}^S .$$

The $\hat{m}_{j,t}$ serve as estimates of the true $m_{j,t}$ innovations. From equation (24) it is clear that if there is zero serial correlation in the $\hat{m}_{j,t}$ processes then there also is zero serial correlation in the $\hat{m}_t$ series.

Cosslett and Lee (1985) provide a test for first order serial correlation in latent discrete variable models based on the $\hat{m}_t$ residuals. Given a set of residuals defined by equation (22), the test statistic:

$$(26)\quad \frac{\sum_{t=2}^{T} \hat{m}_t\, \hat{m}_{t-1}}{\sum_{t=2}^{T} \hat{m}_t^2\, \hat{m}_{t-1}^2} ,$$

is asymptotically normally distributed. In this case the test statistic was found to have a value of .1658 with a marginal significance level of 87%. This indicates that it is very difficult to reject the null hypothesis of zero serial correlation in the residual series.

A Lagrangian Multiplier (LM) test for serial correlation in the residual series also was conducted. This procedure allows a test either for serial correlation at a single lag (which may be greater than one) or at a series of lags. For example, one could test the hypothesis that ρ_K equals zero at a particular lag K in:

$$(27)\quad \hat{m}_t^S = \omega_o + \sum_{r=1}^{7} X_{r,t}\omega_r + \rho_K \hat{m}_{t-K}^S + v_t;$$

where v_t is a white noise innovation, $X_{r,t}$ is the r'th explanatory variable in X_t, and the ω_r are coefficients. Alternately one may test jointly the hypothesis that ρ_K equals zero at K different lags in:

$$(28)\quad \hat{m}_t^S = \omega_o + \sum_{r=1}^{7} X_{r,t}\omega_r + \rho_{k1}\hat{m}_{t-k1}^S + \rho_{k2}\hat{m}_{t-k2}^S + \ldots + \rho_K \hat{m}_{t-K}^S + v_t$$

The test statistic here is:

$$(29)\quad q\left[\frac{SSR_r - SSR_{ur}}{SSR_{ur}}\right]\left[\frac{T-7-1}{q}\right] \sim \chi^2_{(q)} \;;$$

where: q is the number of lagged $\hat{m}_{t-k}$'s, SSR_{ur} is the sum of squared residuals ($\hat{v}_t$) from a regression run on eqtn. (27) or (28) and SSR_r is the sum of squared residuals from a regression of (27) or (28) with the restriction that the coefficients on all lagged $\hat{m}_{t-k}$ be equal to zero. Results of these tests are reported in table 3. In each case, the null hypothesis of zero serial correlation could not be rejected at the 5% significance level.

A third test is to simply plot the estimated autocorrelations of the residual series and check for significant values. This is done in

Figure 16. The boundaries determined by plus and minus two standard deviations of the estimated autocorrelations approximate the 5% critical values for a test that an autocorrelation is equal to zero. None of the estimated autocorrelations fall outside this boundary; therefore, it again can be concluded that there is no serial correlation in the residual series.

The assumption that the innovation processes are normally distributed also was tested. The test procedure was conducted as follows. For each process j, create a sample of $\hat{m}_t$ residuals, with only those observations included for which $\text{Postprob}_{j,t}$ is greater than .5. These are the residuals which most likely were produced by a rule j money regime. The measures of skewness and kurtosis for this sample then are tested for consistency with the normality assumption. The test statistics and their marginal significance levels are reported in table 5. It was not possible to reject the null hypothesis of normality for any one of the four innovation processes at the 5% significance level based on either skewness or kurtosis.

The econometric model also is based on the assumption that the Fed's choice of a money rule at time t is independent of its decision in the previous period. In other words, $\hat{\lambda}_{j,t-1}$ does not enter the N_t vector. Use of the logistic distribution in equation (15) is valid only if this assumption is met. Cosslett and Lee (1985) also provide a procedure for testing this hypothesis. Define a fitted indicator variable, $\hat{D}_{j,t}$, as follows:

$$(30)\quad \hat{D}_{j,t} = \begin{cases} 1 & \text{if } Postprob_{j,t} \geq .5 \\ 0 & \text{if } Postprob_{j,t} < .5 . \end{cases}$$

In other words $\hat{D}_{j,t}$ is equal to one in those periods which have been identified as most likely associated with a rule j money regime. If the dynamics of the model have been misspecified by omitting $\hat{\lambda}_{j,t-1}$ from N_t, there will be serial correlation in the errors: $\hat{D}_{j,t} - \hat{\lambda}_{j,t}$. The null hypothesis here then is that there is no serial correlation in these errors. The test statistic:

$$(31)\quad \frac{\sum_{t=2}^{T} \left[\hat{D}_{j,t} - \hat{\lambda}_{j,t} \right] \left[\hat{D}_{j,t-1} - \hat{\lambda}_{j,t-1} \right]}{\sum_{t=2}^{T} \left[\hat{D}_{j,t} - \hat{\lambda}_{j,t} \right]^2 \left[\hat{D}_{j,t-1} - \hat{\lambda}_{j,t-1} \right]^2}$$

follows an asymptotic standard normal distribution. Results of this test for each of the four rules are provided in table 4. For each of the four rules it was not possible to reject the null hypothesis at the 5% significance level; therefore, the assumption that money rule decisions are made independently each period is accepted. The fitted $\hat{\lambda}_{j,t}$'s are provided in table 6.

A test of the accuracy of regime classification information obtained from the model is provided by Hajivassiliou (1986). Again divide the data sample into monetary regimes based on the $\hat{D}_{j,t}$ indicator defined in equation (30). Now run separate regressions for each money rule using only those data points that $\hat{D}_{j,t}$ associates with that rule. Gather the resulting estimates of the parameters of all the money rules into a vector $\tilde{\gamma}$. The variance-covariance matrix of this vector is denoted $\tilde{\Sigma}$. The estimates obtained from the maximum likelihood method are denoted as $\hat{\gamma}$ with variance-covariance matrix $\hat{\Sigma}$. If the regime classification information is correct, then the $\tilde{\gamma}$ estimates are both consistent and efficient while the $\hat{\gamma}$ estimates are only consistent. This naturally leads to a Hausman type specification test. Construct the test statistic:

$$(32) \quad S = (\tilde{\gamma} - \hat{\gamma})'(\tilde{\Sigma} - \hat{\Sigma})^{-1}(\tilde{\gamma} - \hat{\gamma}).$$

This statistic follows a χ^2 distribution with degrees of freedom equal to the rank of $\hat{\Sigma}$. The null hypothesis here is correct regime classification. Calculation of the S statistic for this model resulted in a value of 6.0706, which is distributed as a χ^2 with 32 degrees of freedom. This statistic has a marginal significance level of .999, resulting in a failure to reject the null hypothesis.

Finally, one can test the out-of-sample fit of the switching model. As was mentioned above the model can be used to form forecasts of money growth which allow for the possibility that any one of the policy rules identified in the estimation sample will be in place. Given the estimates of the γ_j and β_j vectors of coefficients, the procedure for forming one-step-ahead projections is quite simple. Use the estimates of β_j to form $\hat{\lambda}_{j,\tau}$, where τ refers to the time for which the forecast of money growth is made. The forecast then is given by:

$$(33)\quad \hat{M}^S_\tau = \sum_{j=1}^{4} \hat{\lambda}_{j,\tau}\, \hat{M}_{j,\tau} \,;$$

where:

$$(34)\quad \hat{M}_{j,\tau} = X_\tau \gamma_{j,\tau} \,.$$

Since N_t and X_t contain only lagged variables, these explanatory variables are observed in the case of one-step-ahead forecasts. If one desires to form a projection for money growth more than one period in the future, N_τ would have to be forecast before forming $\hat{\lambda}_{j,\tau}$. Also X_τ in eqtn. (34) would refer to a forecast of these explanatory variables.

Using available 1986 data, a set of one-step-ahead forecasts for that year were conducted. These were formed using actual data series N_t and X_t, however the parameter estimates were not updated by reestimating the model with an additional data point each period. It turned out that for all the months in 1986, the $\hat{\lambda}_{j,t}$ probabilities were virtually equal to one for rule one and equal to zero for all other rules. The strength of the switching model, identifying the more restrictive rules two, three, and four, then was not useful for that year. As a result, the RMSE for the predictions of the switching model is virtually identical to that of projections made from OLS estimates. However, it still is important to note that the switching model did not suffer a serious decline in fit (compared to OLS) by moving out of sample.

CHAPTER VI

INTERPRETATION OF THE RESULTS

As described above, the post-probabilities listed in table 7 are used to identify the dates at which each money rule was most likely used. Two characteristics of these probability series are immediately evident. First, at any given date, the probabilities for each rule tend to be very close to either zero or one. The sample separation for the model is exceptionally good. The problem of distinguishing between two or more rules with high probabilities at the same date simply does not arise. Secondly, high probabilities for a specific rule j tend to run consecutively for several months. A set of consecutive months in which the same rule is in place then is defined as a monetary "regime". The date and duration of each regime is listed in table 8. Notice that the data does separate nicely into regimes without a specification which forces the Fed's choice of money rule to depend on last period's decision. A money rule is maintained for several months because the economic conditions which lead to its adoption tend to persist for some time.

The summary statistics in table 9 show that rule one has been associated with the highest rate of money growth. Although the coefficient on log differenced unemployment is not significant, it seems clear on examination of Figure 4 that rule one is adopted when the Fed becomes concerned with the unemployment rate. The Fed replaced tighter money rules with rule one when the unemployment rate increased to unusually levels both in early 1975 and in the second half of 1982. It seems that rule one is used in an attempt to pull the economy out of recession and to accomodate the early to middle stages of the following business expansion. The significant positive coefficient on the stock index could be interpreted as an attempt by the Fed to accomodate the money demand of a growing economy. The significant negative coefficient on the log differenced consumer price index shows that the growth rate of money is reduced as the inflation rate increases. It seems that an increase in prices is interpreted by the Fed as a signal that monetary policy has been overly accomodative.

The second money rule seems to occupy a middle ground between rules one and three. The money growth rate is above average; however, the rule seems to have been chosen in response to rising inflation. It was used for an extended period on two occasions. Eleven of the sixteen months from Dec. 1973 to Feb. 1975 are associated with rule two. It was used again for nineteen months beginning in April 1978 and lasting until Oct. 1979. Figures 2 and 3 show that on both occasions inflation was high (between 9% and 15%) and interest rates were at moderately high levels. The γ_2 coefficients indicate that money growth was decreased as the inflation rate increased and further reduced when nominal interest rates rose. The negative response to increases in nominal interest rates could have been the result of a belief by the Fed that private agents were beginning to add an inflation premium to the interest rate. Money growth was increased if industrial production grew at a faster rate due to the fact that the increase in output would cause money growth to have a smaller effect on prices.

Rule two also was used for six months from June to November of 1980. At that time, unemployment had increased while both inflation and interest rates had fallen following the imposition of tight money rules in the preceding months. Rule two was used to relax to some extent the earlier monetary restraint, but was abandoned in favor of the more restrictive rules when inflation and interest rates both began to rise again. These months in late 1980 have been described as a period in which the Fed "wavered" from its generally restrictive monetary policy covering the Oct. 1979 to Oct. 1982 period [Duesenberry(1983) for example]. Finally, rule rule two is associated with several short transition periods between the tight money regimes associated with rules three or four and the more rapid money growth of rule one.

The third rule is best described as a tight money rule. Table 9 shows that the average growth rate of the money supply in rule three regimes is approximately one-third less than in periods associated with rules one or two. Figure 2 shows that rule three is most directly associated with periods in which the interest rate is high, usually in the range of 8% to 13%, with a mean of approximately 10.5%. Examination of Figure 3 shows that the link between the choice of rule three and the inflation rate is not quite as certain. It has been used in periods of both moderate and high inflation, although the mean inflation rate is fairly high at 8%. With the exception of the Nov. 1981 to May 1982 regime, the rule was used in periods of low to moderate unemployment, generally in the range of 5% to 7%. The β_3 coefficients tend to support these observations. The large positive coefficient on the treasury bill rate and the large negative coefficient on unemployment indicate that the probability of this rule being chosen is much higher in periods of low unemployment and high interest rates. The γ_3 coefficients also support the description of this rule given above. The large negative coefficient on lagged money growth is consistent with a tight money rule being imposed following regimes associated with the faster growth rates of rules one and two. The significant negative coefficient on lagged increases in the treasury bill rate indicates that money growth was reduced as interest rates increased at a faster pace.

The fourth money rule was used in only one extended period, the eleven months from December 1980 to October 1981. It seems logical that this unique rule would be associated with the most extreme economic conditions in the sample period. The treasury bill rate was very high in these periods, ranging from 9% to 15.5%, with a mean of approximately 14%. As shown in figure 2, these were the highest interest rates in the sample period. The average inflation rate also was at a high level, with a mean of 9.7%. In addition to these problems, the average unemployment rate was 7.3%, quite high by postwar standards. Table 9 shows that on average money growth under this rule was extremely tight; however, it varied within a fairly wide range. Rule four seems to have been used when the Fed was determined to end high inflation and the associated inflationary expectations despite the fact that unemployment was high. This is verified by the large positive coefficient on the treasury bill rate in the β_4 vector. The γ_4 coefficients also are consistent with this description, as money growth shows a significant negative response to both interest and inflation rates. What is perhaps most striking about this rule is the extreme negative response to lagged inflation (ldcpi) in γ_4. There also is a significant negative coefficient in γ_4 on the log differenced unemployment rate, indicating that the Fed was reducing money growth in spite of the fact that unemployment was rising. The negative coefficient on the unemployment rate in β_4 indicates that for this rule to be used, interest and inflation rates had to be extremely high in order to offset the Fed's concern with unemployment.

The Fed's selection of money rules seems to depend critically on the unemployment rate, the inflation rate, and the level of nominal interest rates. The exchange rate apparently plays a relatively minor role in the selection process. These results are evident from the results of the likelihood ratio tests on the β_j coefficients and from inspection of Figures 2-5. Figure 2 shows a clear link between the interest rate and the money rule chosen by the Fed. Rule one is chosen when interest rates are at their lowest level. As they begin to rise, rule two is chosen. When they reach high levels rule three is imposed. Finally, rule four was used when they had reached the highest levels in the data sample. One might argue that the direction of causality runs in the reverse direction, that successively tighter money rules caused interest rates to rise. Without some formal causality test, it cannot be determined which argument is correct, and existing causality tests, unfortunately, are not designed for the type of model used in this paper. Figure 2 does seem to show, however, that interest rates begin to rise before the tighter money rules are imposed. It also seems clear from figure 3 that the Fed shifts away from rule one as inflation begins to increase.

Figure 4 clearly shows the Fed abandoning the tight money rules in favor of rule one when unemployment reached extremely high levels in early 1975 and again in early 1983. The importance of the unemployment rate to the Fed's decision process is further demonstrated by the following incidents. Rule three was used for a period beginning in May 1974, but by Aug. of of that year the unemployment rate had begun to increase and rule three was abandoned in favor of rule two. The unemployment rate continued to increase, rising to a level above 8%, and rule two was abandoned in favor of rule one. In a second episode, rule three was imposed in Nov. 1979, but was abandoned in favor of rule two when the unemployment rate had risen to near 8% in May 1980. Finally, rule three again was used beginning in Nov. 1981, but was replaced by rule two in May 1982 when the unemployment rate had risen to approximately 9%. Throughout the sample period there is a clear tendency for the Fed to move to less restrictive money rules when unemployment significantly increases.

The Fed's monetary policy during this sample period then can be summarized as follows. Rule one seems to be aimed at reducing unemployment by allowing the money supply to grow at a relatively fast rate. It is adopted during times of high unemployment, maintained as the economy begins to expand, and dropped when the problem of high unemployment has been replaced with that of rising inflation. Rule two seems to be adopted as an initial response to an increase in the inflation rate even though it corresponds to only slightly lower money growth than is associated with rule one. If the higher inflation begins to be accompanied by increases in nominal interest rates, rule two is abandoned in favor of rule three and a significant reduction in money growth. Rule four, which averaged the slowest rate of money growth of all the rules, was adopted when inflation was high and interest rates were at the highest levels found in the sample period. It seems clear that rules three and four were intended to reduce both actual and anticipated inflation. When the problem of high inflation and accompanying high nominal interest rates was replaced with high unemployment, the Fed again turned to the faster money growth rates of rules one and two. The Fed basically seems to have followed a countercyclical monetary policy with its selection of rules. When unemployment rose to high levels, it chose fast money growth rules. When inflation and nominal interest rates became high, it chose restricted money growth rules.

It may be noted that the regimes associated with rules two, three, and four are of fairly short duration in terms of the number of months involved. However, it also should be noted that these rules are adopted in response to unusual economic conditions. Being unusual means that these conditions, and the associated money rules, should be found in only a relatively small subset of the sample months. Also, consider the fact that "short" or "long" duration is a relative term. While relaxed rule one might need to be maintained for two or three years before it is considered a "long" regime, six months of the tight money of rule three could seem to be a very long regime during that time.

A final way of demonstrating how monetary rule have varied through this set of sample months is to recognize that the reaction function can be written as:

$$(35)\quad M_t^S = \sum_{j=1}^{4} \text{Postprob}_{j,t}\left[X_t \gamma_j + m_{j,t} \right].$$

The fitted value of money growth then can be written as:

$$(36)\quad \hat{M}_t = X_t \hat{\gamma}_t .$$

The fitted coefficient vector $\hat{\gamma}_t$ is given by:

$$(37)\quad \hat{\gamma}_t = \sum_{j=1}^{4} \left[\text{Postprob}_{j,t}\right]\left[\gamma_j \right],$$

where $\hat{\gamma}_j$ is the estimate of γ_j. There then is a fitted coefficient for each month, and this coefficient may vary from month to month. A plot of these coefficients through time then shows how the Fed's money rule has evolved. These plots are given in Figures 6 through 13.

All the plots show substantial instability in the fitted coefficients over the period ranging from November 1979 to August 1982. Over this time the Fed was alternating between rules two, three, and four. It is interesting to note that this period corresponds closely to the set of months between the Fed's October 1979 and October 1982 changes in operating procedures. Some of the plots show the instablity beginning as early as April 1978 with the adoption of rule two. An earlier period of instability also is indicated in several of the plots. This period ranges from approximately April 1973 to February 1975. During these months the Fed alternated between rules two and three.

The Fed's monetary policy behavior during this sample period is consistent with the actions of a monetary authority facing the time consistency problem discussed by Kydland and Prescott (1977). In their model, the optimality of a money rule depends on the structural constraint imposed by the expectations of private agents. Recall that nominal interest rates may be broken down by the Fisher equation into two components, an expected real rate of interest and a premium for expected inflation. Now consider the Fed's use of money rule one. Rule one was used when inflation and nominal interest rates were low. These conditions indicate that the rate of inflation (and money growth) expected by private agents was probably fairly low. The Friedman-Phelps natural rate hypothesis predicts that the rapid money growth associated with this rule was most likely to be effective in reducing unemployment during these periods. As long as the rule was judged to be effective, or optimal, it was maintained. This was the case in the months lasting from March 1975 to March 1978. However, significant increases in inflation and nominal interest rates may have been taken by the Fed as signals that private agents had begun to expect rapid money growth and that this rule no longer would be effective in reducing unemployment. Rule one had become suboptimal and was abandoned. This occurred in April 1978.

Next consider the Fed's use of rules three and four. These rules were in place during periods associated with high inflation and high nominal interest rates, such as the majority of the months from November 1979 to May 1982. These conditions are consistent with expectations by private agents of fast money growth and high inflation. To reduce unemployment in this situation, the Fed would have to expand the money supply at a very rapid rate (greater than the high rate expected by the public) and risk the possiblity of extremely high inflation. The Fed instead chose to respond with the very restrictive money growth of rules three and four. This choice meant expanding the money supply at a slower rate than was anticipated by the public and could be expected (by the Fed) to lead to an increase in unemployment. Rules three and four then were chosen when the benefits of reducing actual inflation and inflationary expectations were judged to be great enough to outweigh the costs of higher unemployment. While it is possible that reducing the inflation rate may be accomplished simply by restricting the growth rate of the money supply, reducing inflationary expectations may be a much more difficult task. This requires that the credibility of the Fed's anti-inflation policy be established. The public must believe that the Fed is firmly committed to a policy of maintaining low money growth and inflation. Continuing to follow rules three and four as unemployment increased to higher levels may have been partly intended to establish the Fed's credibility as an inflation fighter, thereby reducing inflationary expectations. Once the goals of low inflation and low inflationary expectations were attained, the ability to reduce unemployment by using the faster money growth rules was regained. The restrictive rules were dropped and the Fed returned to faster money growth rules. Money rule one was readopted in September of 1982.

Duesenberry's theory of political pressure also is a potential explanation for the Fed's pattern of rule selection. However, this explanation is not as convincing as the theory of time inconsistency. Increases in the unemployment rate to high levels did coincide with the Fed's choice to adopt the fast money growth rule one in March 1975 and again in Sept. 1982. Further, the tight money of rule three was dropped in favor of the relatively faster money growth of rule tow in June 1980, again during a time of high unemployment. However, unemployment was above 8% in March 1975, near 8% in June 1980, and approaching 11% in Sept. 1982. If political pressure was the cause of these rule changes, then the Fed evidently was able to resist the pressure until unemployment was at levels that were unusually high for the post-war United States. Further, the Fed did not make the rule changes until both inflation and nominal interest rates had been reduced from their previous high levels. If the Fed bowed to political pressure in these instances, it did not seem to do so until its tight money rules had achieved their goals.

The preceding description of monetary policy during this period is supported by the work of Romer and Romer (1987). They looked for evidence of anti-inflation shocks in the published reports of the Board of Governors and the Federal Open Market Committee. They found evidence of such a shock in comments made during April 1974. The Fed spoke of "the persistence of inflation and of inflationary psychology" and "the need for policy actions to counter inflationary expectations". The Fed's central considerations at the time were listed as "the rise in market interest rates" and "the rapid advances in prices and costs". The switching model identifies rule three regimes lasting from July to November of 1973 and again from May to August of 1974. Both are close to the time of these statements. These remarks by the Fed are consistent with the explanation given above for the Fed's selection of money rule three. The Fed was concerned about high inflationary expectations and indicated that its observation of high nominal interest rates was a source of this concern.

Romer and Romer also agree with the conclusions drawn from the switching model regarding policy in the period from 1975 to 1978. Although they found several comments by the Fed describing its policy as anti-inflationary, they conclude that it was not. They point both to the fact that target money growth rates were lowered very little and to several comments indicating that the Fed was unwilling to follow a strongly anti-inflationary policy and risk the possibility of high unemployment. The switching model identifies the period from March 1975 to March 1978 as a rule one regime. Rule one selection was described as being aimed at reducing unemployment rather than inflation.

By early 1978, the Romers found evidence that the Fed was preparing to implement tighter money rules. In May 1978, the Fed stated that "...it would be desirable for growth in real output to diminish in the second half of this year." In August 1978, it stated that "...an appreciable slowing of inflation would prove more difficult to achieve than previously had been anticipated." They also point to the fact that from August to November of that year the Fed increased the discount rate from 7.25 to 9.5% and that it raised reserve requirements in November. The switching model finds the Fed moving toward slower money growth at this time by abandoning rule one in favor of rule two in April 1978. The Fed's statements also indicate that it was considering further reductions in money growth and beginning to accept the risk of an increase in unemployment. Both the switching model and the Romers identify the October 1979 change in Fed operating procedures as the switch to restrictive money growth. The Fed stated that this action was taken in part to "curb speculative excesses in financial, foreign exchange, and commodity markets, thereby dampening inflationary forces in the economy". The Fed had returned to rule three in order to reduce inflationary expectations.

Given the benefit of hindsight, the Fed's policy behavior during this sample period is subject to criticism. It allowed inflation and nominal interest rates to reach very high levels before acting to reduce money growth in both 1973 and 1979. In both cases, it is possible that inflation and inflationary expectations had reached such high levels that the Fed's credibility as an inflation fighter was damaged. It may have been forced to impose the restricitve rules three and four to reestablish that credibility. Unfortunately, this also meant that the reductions in money growth probably were unanticipated by private agents and were a contributing cause of the 1975 and 1979 recessions. The Fed probably should have moved to slower money growth before its credibility had diminished. The reductions in money growth then probably could have been smaller and would not have resulted in such large increases in unemployment.

CHAPTER VII

A MARKOV SWITCHING MODEL OF M-1 MONEY

As was discussed in the introductory chapter, good forecasts of money supply movements are of great importance. It is often the case that relatively simple time series models outperform complicated structural econometric models in forecasting economic series. For this reason, such models have become very popular. Also, the previous chapters have shown that there is substantial instability in the coefficients of a linear reduced form econometric money supply equation. This caused the econometric model to become quite complicated. It then is imporant to investigate whether the complication of parameter instability can be avoided by using a time series model. If the instability is still present, it is important to develop a time series model which can account for it and hopefully provide even better forecasts.

This chapter presents a time series model of United States M-1 money which allows for discrete shifts in the parameters describing the motion of the monetary series. In this model, the money supply may follow one of two possible autoregressive processes. For each sample period, a probability is assigned to the event that a particular process has been realized. Those periods for which money is most likely following the first process are referred to as realizations of state one. The remaining periods then are associated with the second process and state two. Both the coefficients of the autoregressions and the conditional variance of money are allowed to differ across states. The realization of the monetary state in each period is assumed to be determined by a first order Markov process. The model is estimated using monthly, deseasonalized data drawn from Jan. 1973 to Dec. 1985. The data are log differenced, so all references to "money" below refer to the growth rate of M-1.

As described above, this model allows the monetary series to follow one of two possible autoregressive processes in each time period. For this paper, the two processes have been specified as fourth order autoregressions. A discrete indicator, s_t, is used to capture the monetary state at each date. The indicator is described by:

$$(38)\quad s_t = \begin{cases} 0 & \text{in monetary state one,} \\ 1 & \text{in monetary state two.} \end{cases}$$

The monetary process then is given by:

$$(39)\quad M_t^S = (c_2 * s_t) + [c_1 * (1-s_t)] + \sum_{j=1}^{4} \Big[(\rho_{2,j} * s_t) + [\rho_{1,j} * (1-s_t)] \Big] \Big[M_{t-j}^S - [(c_2 * s_{t-j}) + [c_1 * (1-s_{t-j})]] \Big] + (m_{2,t} * s_t) + [m_{1,t} * (1-s_t)];$$

where: c_1 and c_2 are constants associated with state one and state two respectively, $\rho_{1,j}$ and $\rho_{2,j}$ are the autoregressive coefficients on the j'th lag of money in state one and state two, and $m_{1,t}$ and $m_{2,t}$ are the innovations to money in state one and state two. Each of the innovation processes has its own standard deviation, σ_j. Notice that the constant subtracted from the j'th lag of money depends on the state which was realized at time t-j.

The above equation (39) includes the current value and four lags of the indicator s_t. Each of these five indicators may take a value of zero or one according to (38). There then are 32 possible combinations of the five (0,1) indicators, each implying a reduced form of equation (39) at each date in the sample. For example, if $s_t = s_{t-1} = s_{t-2} = s_{t-3} = s_{t-4} = 0$, equation (2) reduces to:

$$(40)\quad M_t^S = c_1 + \sum_{j=1}^{4} \rho_{1,j}\left[M_{t-j}^S - c_1 \right] + m_{1,t} .$$

However, if s_{t-4} were equal to one (while the other indicators remain at zero) the equation changes to:

$$(41)\quad M_t^S = c_1 + \sum_{j=1}^{4} \rho_{1,j}\left[M_{t-j}^S - c_1 \right] + \rho_{2,4}{}^{*}\left[M_{t-4}^S - c_2 \right] + m_{1,t}.$$

As mentioned above, it is assumed that the $\{s_t\}$ series follows a first order Markov process. This means that if the money supply was in a particular state last period, there is some probability that it will be in that same state this period. There also is some probability that it will switch to the other state this period. This type of switching mechanism simply exploits the pattern of realization of states found in the data sample. It is very much like using the pattern of correlation between the current value of a series and lagged values to estimate a standard ARIMA model. The Markov process is given by:

$$(42)\quad \begin{cases} \text{Prob}[s_t = 0 | s_{t-1} = 0] = q, \\ \text{Prob}[s_t = 1 | s_{t-1} = 0] = (1-q), \\ \text{Prob}[s_t = 1 | s_{t-1} = 1] = r, \\ \text{Prob}[s_t = 0 | s_{t-1} = 1] = (1-r). \end{cases}$$

The q and r probabilities are given by:

$$(43)\quad q = \exp\left[-1*(b_1)^2 \right];$$

$$(44)\quad r = \exp\left[-1*(b_2)^2 \right];$$

where b_1 and b_2 are parameters to be estimated.

Using an algorithm developed by Hamilton (1988, 1989), it is possible to formulate the probability that each of the 32 possible reduced forms of (39) were in place at each date. This algorithm also builds the log likelihood function for the model. This function is maximized (here using the BHHH algorithm) to obtain estimates of the parameters: $\rho_{1,j}$, $\rho_{2,j}$, c_1, c_2, σ_1, σ_2, b_1, and b_2.

One additional probability measure should be noted. As noted by Hamilton, the unconditional probability that s_t will be equal to one is given by:

$$(45)\ rho = \frac{1-q}{(1-r) + (1-q)} = Prob[s_t = 1].$$

Estimates of all the parameters as well as the resulting values of q, r, and rho are given in table 11. The fitted probabilities for monetary states one and two are listed in table 12 as Prob1 and Prob2 respectively. It should be noted that an earlier version of this model specified with AR(1) processes resulted in fourth order serial correlation in the residuals. The plotted autocorrelations of the residual series (shown in Table 13) are not greater than two standard deviations. The AR(4) specification then seems to be correct.

Estimates of a standard fixed coefficient AR(4) money growth model are provided in table 14. The difference in log likelihoods between the Markov and the fixed coefficient model is significant at the 1% level, indicating that the fit of the model is significantly improved by using the Markov switching model.

The fitted probabilities listed in table 12 divide the monetary series into two states. Notice that the sample separation in this model is quite good. The fitted probabilities tend to be close to either zero or one. The first money process is the dominant case here since 114 of the 156 sample months are associated with state one. The unconditional probability that state two will occur (given by rho) is only approximately .28. Realization of state two then can be described as a deviation from normal money behavior. This deviation occurs only twice, in the eight months from March 1973 to Oct. 1973, and in the longer period from April 1980 to Jan. 1983. This second period roughly corresponds to the set of months between the Fed's

October 1979 and October 1982 changes in operating procedure.

Two immediate observations can be made upon examining the parameter estimates for the two processes. First, the average money growth rate, as measured by the two constants, does not differ by very much across the two states. However, the volatility of the money innovation process (as measured by the standard errors of the the two processes) increases dramatically upon transition into state two. These results indicate that the Fed's change in operating procedure resulted in a deterioration in the fit of the time series model. This was true even here where one has the full set of state two months to use in estimation. During that period money growth would have been extremely difficult to forecast.

The unconditional standard deviation of log difference M-1 also was much higher in state two. In state one periods it was equal to .00596. In state two periods it was equal to .0074. The Markov switching model then seems to be separating the money growth series into two processes based on the volatility of money growth. The state one process is characterized by low conditional and unconditional variance, while state two has much greater conditional and unconditional variance. This result is evident on inspection of Figure 17, which plots money growth and shows the two states.

As mentioned in the introduction, these results are consistent with those obtained earlier using a four-rule Goldfeld-Quandt switching model. Both models find deviations from the "normal" money rule, or process, in 1973 and from 1980 to 1982. The difference being that the Goldfeld-Quandt model also picks up deviations in 1974 and 1979. Both models also point to the 1980-1982 period as being a time of unusual volatility in the money series. The Markov model captures this with the increase in the variance of money. The Goldfeld-Quandt model finds three different monetary rules (exceptions to the normal rule) being alternately used.

CHAPTER VIII

CONCLUSION

This paper has used the technique of switching regressions to provide both an econometric model and a time series model of money growth which are capable of accounting for changes in the parameters of money supply equations. It has been shown that the fit of an estimated reduced form money supply equation is significantly improved by allowing for such rule changes. The estimated econometric model identifies four money rules which were used over the sample period of January 1973 to December 1985. The evidence presented indicates that the Fed moves to more restrictive money growth rules as inflation increases and (possibly more importantly) as inflationary expectations begin to be built into nominal interests. Increases in the unemployment rate seems to have caused the Fed to abandon restrictive policies at several dates. However, the unemployment had risen to unusually high levels while interest and inflation rates had decreased before the Fed relented and moved back to less restrictive rules. It was found that the period falling between the Fed's Oct. 1979 and Oct. 1982 changes in operating procedures was a time of very high volatility in monetary policy, with the Fed alternating between several money rules. The period from mid-1973 to mid-1975 also was found to be a somewhat unstable period.

It also was shown that the fit of a time series model for this period is improved by allowing for parameter variation. Just as with the econometric model, the time series model identifies the period between the Fed's October 1979 and October 1982 changes in operating procedure as a time of extreme volatility in the money growth series. This volatility is captured in the time series model by an increase in the conditional variance of money growth. The large conditional variance for this period indicates that money growth would have been extremely difficult to forecast at that time.

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APPENDIX I

THE MAXIMIZATION ALGORITHM

As described in Chapter IV, the estimates presented in this paper are derived by maximizing the likelihood function given by (16). Several numerical algorithms for solving such a problem exist; however, some trial and error have indicated to this author that the switching model used here is best estimated through the use of the BHHH (Berndt, Hall, Hall, and Hausman) algorithm. In practice, the algorithm minimizes the negative of the likelihood function. Almost all numerical minimization routines proceed by updating initial starting values for the parameters of a model by:

b = b0 - s*P*g;

where P is some positive definite direction matrix, g is the gradient vector of the objective function at the current estimates b0, and s is a scalar steplength adjustment. BHHH is a modified method of scoring algorthm which uses the matrix z'z to approximate the information matrix P. Here z is the matrix of partials of the likelihoods with respect to the parameters. The standard errors reported in the tables of maximum likelihood estimates are based on the value of this direction matrix at the final iteration.

A problem encountered during estimation is that the algorithm (and all other algorithms tried) in this application depends heavily on good starting values. Unfortunately there is little or no prior information available to base this choice on, so a great deal of trial and error is required. The problem basically is that unless starting values are reasonably "close" to the true minimum, the direction matrix will not be positive definite and the algorithm will break down. A suitable direction in which to move the parameters cannot be found. The starting values for the probability coefficients are especially important. If the starting values set the probability that one of the rules occurs very close to zero for all periods, the coefficients of that money rule can take virtually any value without affecting the value of the likelihood function. The algorithm will not be able to find a direction to update these parameters which will decrease the value of the function, so the algorithm breaks down. With some experience, this problem is not too severe for two rule models. However, it remains a significant problem in the estimation of three and higher rule models.

For the likelihood function used in this paper, BHHH outperformed both the BFGS (Broyden-Fletcher-Goldfarb-Shanno) and the DFP (Davidon-Fletcher-Powell) algorithms. DFP was found to be extremely slow. BFGS is somewhat faster than BHHH; however, it is even more sensitive in accepting starting values. If the option is available, an optimal estimation strategy would be to use BHHH for the first several iterations until it is believed that the objective function is reasonably close to a minimum, then switch to BFGS to increase estimation speed. In any case, BHHH should be used on the final iteration since it provides better estimates of the standard errors.

Appendix II

Estimation Results

Estimation results are reported in tables 1-14.

The following notation is used to refer to specific data series.

FM1 = M-1 money.

TBILL = six month treasury bill rate (auction).

CPI = consumer price index (urban).

UNEMP = civilian unemployment rate.

EXVUS = trade weighted value of the U.S. dollar.

FSP = Standard & Poor's index of stock prices.

IP = index of industrial production.

A series beginning with "LD" is in log first differenced form.

All series used were obtained from Citibase.

Table 1 contains the estimated parameters of the four rule reaction function.

The γ_j coefficients are listed on the first page of the table.

The β_j vectors of coefficients are listed on the second page of the table as "Probj.Coeff."

Estimates of the standard errors of the $m_{j,t}$ processes are listed at the end of the table on the second page as "Std.Errors".

The last column in the table listed as "P-Value" gives the marginal significance level of the reported t-statistic for each parameter.

Table 2 lists the likelihood ratio tests from Chapter IV.

Table 3 contains the results of the LM tests for serial correlation in the switching residuls.

Table 4 contains the results of the Cosslett-Lee test for serial correlation in the indicator series, $\hat{\lambda}_{j,t}$.

Table 5 contains the tests for normality of the switching residuals.

Table 6 lists the fitted probabilities $\lambda_{j,t}$. The column listed as "Probj" contains the probabilities that rule j was being used in the listed month.

Table 7 lists the fitted post-probabilities which were used to divide the money growth series into regimes.

Table 8 lists the dates and durations of the individual money regimes as well as the money rule which was most likely used in each one. The regimes reported here correspond to the dashed lines separating table 7 into sections.

Table 9 reports a set of summary statistics for Ldfm1 and the four variables in N_t. Statistics are listed for the overall data sample as well as for the subperiods in which a particular money rule was used.

Table 10 reports estimation results for a single-rule, or fixed coefficient reaction function.

Table 11 contains the parameter estimates for the Markov time series model described in Chapter VII.

Table 12 lists the fitted probabilities for the Markov model.

Table 13 shows a plot of the autocorrelations of the residuals obtained from the Markov model.

Table 14 reports parameter estimates for a single regime (or fixed coefficient) time series model of LDFM1.

Table 1

Maximum Likelihood Estimates
Policy Reaction Function

Dependent Variable: LDFM1
Observations: 156
Degrees of freedom: 105
Log Likelihood: 709.876676

Variable	Coefficient	Std. Error	t-Stat	P-Value
RULE 1:				
Constant	0.009353	0.001651	5.666139	0.000000
Lag1 ldfm1	0.034361	0.133248	0.257870	0.797011
Lag1 ldtbill	-0.000295	0.006579	-0.044805	0.964348
Lag1 ldcpi	-0.822408	0.218592	-3.762297	0.000269
Lag1 ldunemp	-0.002674	0.018819	-0.142092	0.887279
Lag1 ldexvus	-0.021263	0.024809	-0.857057	0.393360
Lag1 ldfsp	0.049529	0.018243	2.714925	0.007744
Lag1 ldip	-0.015487	0.057973	-0.267136	0.789886
RULE 2:				
Constant	0.009371	0.002206	4.248095	0.000038
Lag1 ldfm1	0.107856	0.113083	0.953782	0.342380
Lag1 ldtbill	-0.024077	0.006280	-3.834068	0.000207
Lag1 ldcpi	-0.350500	0.218822	-1.601756	0.112207
Lag1 ldunemp	0.004689	0.017605	0.266326	0.790509
Lag1 ldexvus	0.032017	0.027395	1.168719	0.245158
Lag1 ldfsp	0.019280	0.019097	1.009605	0.315000
Lag1 ldip	0.203242	0.062182	3.268508	0.001454
RULE 3:				
Constant	0.003157	0.000802	3.936301	0.000141
Lag1 ldfm1	-0.353774	0.075101	-4.710647	0.000000
Lag1 ldtbill	-0.023066	0.009789	-2.356280	0.020307
Lag1 ldcpi	0.156996	0.144926	1.083282	0.281159
Lag1 ldunemp	0.017209	0.015677	1.097732	0.274827
Lag1 ldexvus	-0.073467	0.014135	-5.197484	0.000000
Lag1 ldfsp	0.017090	0.009434	1.811576	0.072903
Lag1 ldip	-0.007221	0.046286	-0.156015	0.876320

Table 1
(Continued)

RULE 4:				
Constant	0.030854	0.008906	3.464568	0.000762
Lag1 ldfm1	-0.061711	0.162961	-0.378684	0.705685
Lag1 ldtbill	-0.083485	0.012728	-6.559157	0.000000
Lag1 ldcpi	-2.868660	0.948157	-3.025510	0.003113
Lag1 ldunemp	-0.134383	0.039834	-3.373608	0.001032
Lag1 ldexvus	0.107766	0.032169	3.349971	0.001115
Lag1 ldfsp	-0.050444	0.048639	-1.037119	0.302058
Lag1 ldip	0.021903	0.219144	0.099947	0.920577
PROB2.COEFF:				
Constant	-23.064134	37.518953	-0.614733	0.540057
Lag1 tbill	4.274288	9.732634	0.439171	0.661438
Lag1 unemp	-1.268529	4.166714	-0.304443	0.761391
Lag1 exvus	-0.254330	0.474186	-0.536350	0.592848
Lag1 inflat	3.779029	5.648183	0.669070	0.504916
PROB3.COEFF:				
Constant	-28.564904	48.780131	-0.585585	0.559408
Lag1 tbill	8.943090	11.508761	0.777068	0.438862
Lag1 unemp	-8.217417	8.065084	-1.018888	0.310593
Lag1 exvus	-0.090562	0.403152	-0.224636	0.822698
Lag1 inflat	2.443246	5.367818	0.455166	0.649927
PROB4.COEFF:				
Constant	-53.357260	64.278908	-0.830090	0.408367
Lag1 tbill	10.221404	11.936139	0.856341	0.393755
Lag1 unemp	-5.820027	10.033301	-0.580071	0.563106
Lag1 exvus	-0.229551	0.696489	-0.329583	0.742370
Lag1 inflat	2.859658	5.450141	0.524694	0.600899

Standard Errors of Equations:	RULE 1:	0.003424
	RULE 2:	0.002607
	RULE 3:	0.000984
	RULE 4:	0.000575

Table 2

Likelihood Ratio Tests

H_0:	H_A:	Test Stat.	Distr.	Degrees of Freedom	Marg.Signif. Level
Two Rule Model	One Rule Model	40.66526	χ^2	14	less than 1%
Three Rule Model	Two Rule Model	56.28299	χ^2	14	less than 1%
Four Rule Model	3 Rule Model	60.74641	χ^2	14	less than 1%
Inflation included in set of indicator series.	Inflation excluded from indicator series.	44.562	χ^2	3	less than 1%
Unemploy. included in set of indicator series.	Unemploy. excluded from indicator series.	17.23179	χ^2	3	less than 1%
Exvus included in set of indicator series.	Exvus excluded from indicator series.	5.419472	χ^2	3	.1435

Table 3

Serial Correlation Tests
Four-Rule Residual Series

LM Tests:

H_o: Lagged Correlations	Test Statistic	Degrees of Freedom	Marginal Signif. Level
1,2,3,4	3.4776	4	.4813
1,2,3	2.8906	3	.4088
1,2	1.0560	2	.5866
2,3	2.9101	2	.2334
1	.0319	1	.8582
2	1.0291	1	.3104
3	1.8163	1	.1778
4	.4439	1	.5053

Table 4

Cosslett-Lee Tests for
Serial Correlation in Indicator Series

Tests for serial correlation in $\hat{\lambda}_{j,t}$:

H_o: no serial correlation.

Indicator Series Number	Test Statistic	Marginal Signif. Level
1	.9368	.3488
2	.9446	.3449
3	.3833	.7015
4	-.7862	.4318

Table 5

Normality Tests
Four-Rule Residuals

H_o: test stat.= 0 (normality)

Rule Number	Skewness Statistic	Marg.Signif. Level	Kurtosis Statistic	Marg.Signif. Level
1	-.4202	.1427	.5534	.3472
2	.3515	.3639	-.4135	.6106
3	.6068	.2444	-.4912	.6647
4	.9152	.2580	2.2372	.2500

Table 6
Fitted Prior
Probabilities

DATE	PROB1	PROB2	PROB3	PROB4
1973: 1	1.000	0	0	0
1973: 2	1.000	0	0	0
1973: 3	.952	.048	0	0
1973: 4	0	.998	.002	0
1973: 5	.015	.958	.027	0
1973: 6	.816	.099	.085	0
1973: 7	.002	.269	.729	0
1973: 8	.247	0	.753	0
1973: 9	0	1.000	0	0
1973: 10	0	0	1.000	0
1973: 11	0	.827	.173	0
1973: 12	0	.275	.725	0
1974: 1	0	.287	.713	0
1974: 2	0	.987	.013	0
1974: 3	0	1.000	0	0
1974: 4	0	.981	.019	0
1974: 5	0	.005	.995	0
1974: 6	0	.745	.255	0
1974: 7	0	.664	.336	0
1974: 8	0	.753	.248	0
1974: 9	0	.988	.012	0
1974: 10	0	1.000	0	0
1974: 11	0	1.000	0	0
1974: 12	0	1.000	0	0
1975: 1	0	1.000	0	0
1975: 2	0	.904	0	0
1975: 3	.999	.001	0	0
1975: 4	1.000	0	0	0
1975: 5	1.000	0	0	0
1975: 6	1.000	0	0	0
1975: 7	.971	.029	0	0
1975: 8	0	1.000	0	0
1975: 9	1.000	0	0	0
1975: 10	.456	.544	0	0
1975: 11	.863	.137	0	0
1975: 12	.990	.010	0	0
1976: 1	1.000	0	0	0
1976: 2	1.000	0	0	0
1976: 3	1.000	0	0	0

Table 6
(Continued)

DATE	PROB1	PROB2	PROB3	PROB4
1976: 4	1.000	0	0	0
1976: 5	1.000	0	0	0
1976: 6	1.000	0	0	0
1976: 7	1.000	0	0	0
1976: 8	1.000	0	0	0
1976: 9	1.000	0	0	0
1976: 10	1.000	0	0	0
1976: 11	1.000	0	0	0
1976: 12	1.000	0	0	0
1977: 1	1.000	0	0	0
1977: 2	1.000	0	0	0
1977: 3	.069	.931	0	0
1977: 4	1.000	0	0	0
1977: 5	1.000	0	0	0
1977: 6	1.000	0	0	0
1977: 7	1.000	0	0	0
1977: 8	1.000	0	0	0
1977: 9	1.000	0	0	0
1977: 10	1.000	0	0	0
1977: 11	1.000	0	0	0
1977: 12	.571	.429	0	0
1978: 1	.999	.001	0	0
1978: 2	.606	.394	0	0
1978: 3	.993	.007	0	0
1978: 4	.001	.999	0	0
1978: 5	0	1.000	0	0
1978: 6	0	1.000	0	0
1978: 7	0	1.000	0	0
1978: 8	0	1.000	0	0
1978: 9	.003	.995	.002	0
1978: 10	0	1.000	0	0
1978: 11	0	.997	.003	0
1978: 12	0	.357	.643	0
1979: 1	0	.040	.960	0
1979: 2	0	.602	.398	0
1979: 3	0	.992	.008	0
1979: 4	0	.928	.072	0
1979: 5	0	.974	.026	0
1979: 6	0	.925	.075	0
1979: 7	0	.990	.010	0
1979: 8	0	.986	.014	0
1979: 9	0	.984	.016	0
1979: 10	0	.554	.443	.003

Table 6
(Continued)

DATE	PROB1	PROB2	PROB3	PROB4
1979: 11	0	.012	.950	.038
1979: 12	0	.002	.920	.078
1980: 1	0	.004	.882	.114
1980: 2	0	.901	.029	.070
1980: 3	0	.001	.483	.516
1980: 4	0	0	.015	.985
1980: 5	0	0	.226	.774
1980: 6	0	1.000	0	0
1980: 7	0	1.000	0	0
1980: 8	1.000	0	0	0
1980: 9	0	1.000	0	0
1980: 10	0	1.000	0	0
1980: 11	0	.972	.010	.018
1980: 12	0	0	.048	.952
1981: 1	0	0	.051	.949
1981: 2	0	0	.082	.918
1981: 3	0	0	.100	.900
1981: 4	0	0	.713	.287
1981: 5	0	0	.846	.154
1981: 6	0	0	.132	.868
1981: 7	0	0	.501	.499
1981: 8	0	0	.259	.741
1981: 9	0	0	.312	.688
1981: 10	0	0	.108	.892
1981: 11	0	0	.794	.206
1981: 12	0	.143	.810	.047
1982: 1	.006	.137	.817	.040
1982: 2	0	.001	.652	.347
1982: 3	0	0	.626	.374
1982: 4	.889	0	.107	.003
1982: 5	0	.009	.632	.359
1982: 6	0	1.000	0	0
1982: 7	0	1.000	0	0
1982: 8	0	.986	.006	.008
1982: 9	1.000	0	0	0
1982: 10	1.000	0	0	0
1982: 11	1.000	0	0	0

Table 6
(Continued)

DATE	PROB1	PROB2	PROB3	PROB4
1982: 12	1.000	0	0	0
1983: 1	1.000	0	0	0
1983: 2	1.000	0	0	0
1983: 3	1.000	0	0	0
1983: 4	1.000	0	0	0
1983: 5	.576	.424	0	0
1983: 6	1.000	0	0	0
1983: 7	1.000	0	0	0
1983: 8	1.000	0	0	0
1983: 9	1.000	0	0	0
1983: 10	1.000	0	0	0
1983: 11	1.000	0	0	0
1983: 12	1.000	0	0	0
1984: 1	1.000	0	0	0
1984: 2	.874	.125	.001	0
1984: 3	1.000	0	0	0
1984: 4	1.000	0	0	0
1984: 5	.968	.002	.030	0
1984: 6	.990	0	.010	0
1984: 7	.055	0	.945	0
1984: 8	.053	0	.947	0
1984: 9	.005	0	.995	0
1984: 10	.073	0	.927	0
1984: 11	.868	0	.132	0
1984: 12	1.000	0	0	0
1985: 1	1.000	0	0	0
1985: 2	1.000	0	0	0
1985: 3	1.000	0	0	0
1985: 4	1.000	0	0	0
1985: 5	1.000	0	0	0
1985: 6	1.000	0	0	0
1985: 7	1.000	0	0	0
1985: 8	1.000	0	0	0
1985: 9	1.000	0	0	0
1985: 10	1.000	0	0	0
1985: 11	1.000	0	0	0
1985: 12	1.000	0	0	0

Table 7
Post Estimation
Fitted Probabilities

DATE	POSTPROB1	POSTPROB2	POSTPROB3	POSTPROB4
1973: 1	1.000	0	0	0
1973: 2	1.000	0	0	0
1973: 3	1.000	0	0	0
1973: 4	0	.994	.006	0
1973: 5	.003	.997	0	0
1973: 6	.783	.217	0	0
1973: 7	.002	.124	.875	0
1973: 8	.011	0	.989	0
1973: 9	0	1.000	0	0
1973: 10	0	0	1.000	0
1973: 11	0	.377	.623	0
1973: 12	0	1.000	0	0
1974: 1	0	1.000	0	0
1974: 2	0	1.000	0	0
1974: 3	0	1.000	0	0
1974: 4	0	.955	.045	0
1974: 5	0	.002	.998	0
1974: 6	0	.449	.551	0
1974: 7	0	.049	.951	0
1974: 8	0	.403	.597	0
1974: 9	0	1.000	0	0
1974: 10	0	1.000	0	0
1974: 11	0	1.000	0	0
1974: 12	0	1.000	0	0
1975: 1	0	1.000	0	0
1975: 2	.032	.968	0	0
1975: 3	.999	.001	0	0
1975: 4	1.000	0	0	0
1975: 5	1.000	0	0	0
1975: 6	1.000	0	0	0
1975: 7	1.000	0	0	0
1975: 8	0	1.000	0	0
1975: 9	1.000	0	0	0
1975: 10	1.000	0	0	0
1975: 11	.773	.227	0	0
1975: 12	1.000	0	0	0
1976: 1	1.000	0	0	0

Table 7
(Continued)

DATE	POSTPROB1	POSTPROB2	POSTPROB3	POSTPROB4
1976: 2	1.000	0	0	0
1976: 3	1.000	0	0	0
1976: 4	1.000	0	0	0
1976: 5	1.000	0	0	0
1976: 6	1.000	0	0	0
1976: 7	1.000	0	0	0
1976: 8	1.000	0	0	0
1976: 9	1.000	0	0	0
1976: 10	1.000	0	0	0
1976: 11	1.000	0	0	0
1976: 12	1.000	0	0	0
1977: 1	1.000	0	0	0
1977: 2	1.000	0	0	0
1977: 3	.018	.983	0	0
1977: 4	1.000	0	0	0
1977: 5	1.000	0	0	0
1977: 6	1.000	0	0	0
1977: 7	1.000	0	0	0
1977: 8	1.000	0	0	0
1977: 9	1.000	0	0	0
1977: 10	1.000	0	0	0
1977: 11	1.000	0	0	0
1977: 12	.521	.479	0	0
1978: 1	.998	.002	0	0
1978: 2	.716	.284	0	0
1978: 3	.994	.006	0	0
1978: 4	0	1.000	0	0
1978: 5	0	1.000	0	0
1978: 6	0	1.000	0	0
1978: 7	0	1.000	0	0
1978: 8	0	1.000	0	0
1978: 9	.003	.997	0	0
1978: 10	0	1.000	0	0
1978: 11	0	.997	.003	0
1978: 12	0	1.000	0	0
1979: 1	0	0	1.000	0
1979: 2	0	.629	.371	0
1979: 3	0	1.000	0	0
1979: 4	0	1.000	0	0
1979: 5	0	.918	.080	.001
1979: 6	0	1.000	0	0
1979: 7	0	1.000	0	0
1979: 8	0	1.000	0	0
1979: 9	0	1.000	0	0

Table 7
(Continued)

DATE	POSTPROB1	POSTPROB2	POSTPROB3	POSTPROB4
1979: 10	0	.319	.681	0
1979: 11	0	.005	.995	0
1979: 12	0	.001	.999	0
1980: 1	0	.002	.998	0
1980: 2	0	1.000	0	0
1980: 3	0	0	1.000	0
1980: 4	0	0	0	1.000
1980: 5	0	0	0	1.000
1980: 6	0	1.000	0	0
1980: 7	0	1.000	0	0
1980: 8	1.000	0	0	0
1980: 9	0	1.000	0	0
1980: 10	0	1.000	0	0
1980: 11	0	1.000	0	0
1980: 12	0	0	0	1.000
1981: 1	0	0	.011	.989
1981: 2	0	0	.026	.974
1981: 3	0	0	0	1.000
1981: 4	0	0	0	1.000
1981: 5	0	0	1.000	0
1981: 6	0	0	.061	.939
1981: 7	0	0	1.000	0
1981: 8	0	0	0	1.000
1981: 9	0	0	.073	.927
1981: 10	0	0	0	1.000
1981: 11	0	0	1.000	0
1981: 12	0	.040	.960	0
1982: 1	.001	0	0	.999
1982: 2	0	0	1.000	0
1982: 3	0	0	1.000	0
1982: 4	1.000	0	0	0
1982: 5	0	0	1.000	0
1982: 6	0	1.000	0	0
1982: 7	0	1.000	0	0
1982: 8	0	.999	0	.001

Table 7
(Continued)

DATE	POSTPROB1	POSTPROB2	POSTPROB3	POSTPROB4
1982: 9	1.000	0	0	0
1982: 10	1.000	0	0	0
1982: 11	1.000	0	0	0
1982: 12	1.000	0	0	0
1983: 1	1.000	0	0	0
1983: 2	1.000	0	0	0
1983: 3	1.000	0	0	0
1983: 4	1.000	0	0	0
1983: 5	.115	.885	0	0
1983: 6	1.000	0	0	0
1983: 7	1.000	0	0	0
1983: 8	1.000	0	0	0
1983: 9	1.000	0	0	0
1983: 10	1.000	0	0	0
1983: 11	1.000	0	0	0
1983: 12	1.000	0	0	0
1984: 1	1.000	0	0	0
1984: 2	1.000	0	0	0
1984: 3	1.000	0	0	0
1984: 4	1.000	0	0	0
1984: 5	.999	0	0	0
1984: 6	1.000	0	0	0
1984: 7	.004	0	.996	0
1984: 8	.024	0	.976	0
1984: 9	.008	0	.992	0
1984: 10	.002	0	.998	0
1984: 11	1.000	0	0	0
1984: 12	1.000	0	0	0
1985: 1	1.000	0	0	0
1985: 2	1.000	0	0	0
1985: 3	1.000	0	0	0
1985: 4	1.000	0	0	0
1985: 5	1.000	0	0	0
1985: 6	1.000	0	0	0
1985: 7	1.000	0	0	0
1985: 8	1.000	0	0	0
1985: 9	1.000	0	0	0
1985: 10	1.000	0	0	0
1985: 11	1.000	0	0	0
1985: 12	1.000	0	0	0

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Table 8
Monetary Regimes

Initial Date	End Date	Duration	Rule Used
Jan. 1973 *	March 1973	3 months	Rule one
April 1973	June 1973	3 months	Rule two
July 1973	Nov. 1973	5 months	Rule three
Dec. 1973	Apr. 1974	5 months	Rule two
May 1974	Aug. 1974	4 months	Rule three
Sept. 1974	Feb. 1975	6 months	Rule two
March 1975	March 1978	37 months	Rule one
April 1978	Oct. 1979	19 months	Rule two
Nov. 1979	May. 1980	8 months	Rule three
June 1980	Nov. 1980	6 months	Rule two
Dec. 1980	Oct. 1981	11 months	Rule four
Nov. 1981	May 1982	7 months	Rule three
June 1982	Aug. 1982	3 months	Rule two
Sept. 1982	June 1984	22 months	Rule one
July 1984	Oct. 1984	4 months	Rule three
Nov. 1984	Dec. 1985 **	14 months	Rule one

Table 9
Summary Statistics

	Overall	Rule 1	Rule 2	Rule 3	Rule 4
Ldfm1:					
mean	.00584	.00688	.00672	.00348	.00171
std.dev.	.00501	.00402	.00444	.00450	.00867
minimum	-.0164	-.00236	-.00072	-.00581	-.0164
maximum	.0199	.0178	.0199	.0171	.0171
Tbill rate:					
mean	8.627	7.044	8.595	10.687	13.867
std.dev.	2.687	1.615	1.754	2.111	1.604
minimum	4.513	4.513	5.674	7.259	9.149
maximum	15.548	10.550	13.612	15.100	15.548
Inflation:					
mean	7.272	4.840	10.012	8.804	9.783
std.dev.	4.152	2.590	3.009	5.755	2.568
minimum	-3.682	-3.682	1.455	-1.269	3.868
maximum	21.541	11.918	15.145	21.541	13.649
Unemp.Rate:					
mean	7.147	7.771	6.307	6.577	7.292
std.dev.	1.438	1.278	1.301	1.581	.243
minimum	4.5	4.8	4.8	4.5	6.8
maximum	10.6	10.6	9.7	9.3	7.8
Exvus:					
mean	107.9	117.1	95.0	105.3	99.9
std.dev.	17.9	17.6	9.1	18.5	8.4
minimum	84.7	93.9	84.7	85.5	87.0
maximum	158.4	158.4	119.6	147.6	112.3

Table 10

Maximum Likelihood Estimates
Policy Reaction Function
Fixed Coefficient Model

Dependent Variable: LDFM1
Observations: 156
Degrees of freedom: 147
Log Likelihood: 631.029346

Variable	Coefficient	Std. Error	t-Stat	P-Value
Constant	0.006267	0.001117	5.608743	0.000000
Lag1 ldfm1	0.125243	0.077534	1.615330	0.108377
Lag1 ldtbill	-0.018989	0.004918	-3.861294	0.000160
Lag1 ldcpi	-0.227971	0.125071	-1.822735	0.070368
Lag1 ldunemp	0.006320	0.015755	0.401131	0.688904
Lag1 ldexvus	-0.018282	0.017822	-1.025795	0.306668
Lag1 ldfsp	0.027186	0.010215	2.661415	0.008639
Lag1 ldip	0.086368	0.043681	1.977240	0.049877

Standard Error of the Equation: 0.004237

Table 11
Maximum Likelihood Estimates
Markov Switching Model

Dependent Variable: LDFM1
Observations: 156
Degrees of freedom: 142
Log Likelihood: 629.611156

Variable	Coefficient	Std. Error	t-Stat	P-Value
RULE 1:				
const.	0.005806	0.000608	9.549764	0.000000
ar1	0.151995	0.101024	1.504546	0.134655
ar2	0.044168	0.101334	0.435868	0.663592
ar3	0.324892	0.098484	3.298917	0.001219
ar4	-0.100456	0.096346	-1.042661	0.298872
std.err.eqtn.	0.003404	0.000319	10.668991	0.000000
RULE 2:				
const.	0.005545	0.001442	3.845553	0.000173
ar1	0.282138	0.200475	1.407348	0.161503
ar2	-0.243253	0.297860	-0.816671	0.415480
ar3	-0.046355	0.390852	-0.118599	0.905760
ar4	-0.283962	0.188714	-1.504721	0.134610
std.err.eqtn.	0.006551	0.001089	6.017266	0.000000
PROB.COEFFS.:				
b1	0.121660	0.088751	1.370810	0.172591
b2	0.196657	0.119531	1.645241	0.102125

PROBS.:
q = .985308
r = .962064
rho = .279172

Computation Time: 7 days 48 minutes 46.60 seconds   Iterations: 41

Table 12
Fitted Probabilities
Markov Switching Model

Date	Prob1	Prob2
1973: 1	.80238024	.19761976
1973: 2	.77777868	.22222132
1973: 3	.14551442	.85448558
1973: 4	.29456161	.70543839
1973: 5	.24699057	.75300943
1973: 6	.27786306	.72213694
1973: 7	.36776253	.63223747
1973: 8	.31700889	.68299111
1973: 9	.28312487	.71687513
1973: 10	.45569821	.54430179
1973: 11	.51281712	.48718288
1973: 12	.61971681	.38028319
1974: 1	.75528834	.24471166
1974: 2	.83418582	.16581418
1974: 3	.90303351	.09696649
1974: 4	.90826142	.09173858
1974: 5	.92790504	.07209496
1974: 6	.95497458	.04502542
1974: 7	.97184829	.02815171
1974: 8	.97885009	.02114991
1974: 9	.98208063	.01791937
1974: 10	.98404046	.01595954
1974: 11	.98429340	.01570660
1974: 12	.98245856	.01754144
1975: 1	.95652851	.04347149
1975: 2	.96738508	.03261492
1975: 3	.96373015	.03626985
1975: 4	.96484972	.03515028
1975: 5	.93154279	.06845721
1975: 6	.81354465	.18645535
1975: 7	.88142940	.11857060
1975: 8	.91253071	.08746929
1975: 9	.87336042	.12663958
1975: 10	.85803060	.14196940
1975: 11	.84495325	.15504675
1975: 12	.85202513	.14797487
1976: 1	.90459625	.09540375
1976: 2	.94308908	.05691092
1976: 3	.96353685	.03646315
1976: 4	.97294601	.02705399
1976: 5	.97862410	.02137590

Table 12
(continued)

Date	Prob1	Prob2
1976: 6	.95175590	.04824410
1976: 7	.96346907	.03653093
1976: 8	.97214027	.02785973
1976: 9	.98022127	.01977873
1976: 10	.94248444	.05751556
1976: 11	.93556363	.06443637
1976: 12	.92236279	.07763721
1977: 1	.95060237	.04939763
1977: 2	.96226216	.03773784
1977: 3	.96973133	.03026867
1977: 4	.97899564	.02100436
1977: 5	.96077635	.03922365
1977: 6	.97304685	.02695315
1977: 7	.97721365	.02278635
1977: 8	.98081464	.01918536
1977: 9	.98224620	.01775380
1977: 10	.97951190	.02048810
1977: 11	.98160808	.01839192
1977: 12	.98353059	.01646941
1978: 1	.97994679	.02005321
1978: 2	.96656034	.03343966
1978: 3	.97421497	.02578503
1978: 4	.97301620	.02698380
1978: 5	.94755025	.05244975
1978: 6	.96532316	.03467684
1978: 7	.97015805	.02984195
1978: 8	.97284926	.02715074
1978: 9	.95397926	.04602074
1978: 10	.95840767	.04159233
1978: 11	.97178036	.02821964
1978: 12	.97792733	.02207267
1979: 1	.96992575	.03007425
1979: 2	.97435507	.02564493
1979: 3	.97597712	.02402288
1979: 4	.69916155	.30083845
1979: 5	.67571241	.32428759
1979: 6	.61840887	.38159113
1979: 7	.76161604	.23838396
1979: 8	.84948319	.15051681
1979: 9	.87891712	.12108288
1979: 10	.85881154	.14118846
1979: 11	.85624328	.14375672
1979: 12	.90223393	.09776607
1980: 1	.92896609	.07103391

Table 12
(continued)

Date	Prob1	Prob2
1980: 2	.90091906	.09908094
1980: 3	.82474636	.17525364
1980: 4	.00000141	.99999859
1980: 5	.05755647	.94244353
1980: 6	.00049922	.99950078
1980: 7	.00042369	.99957631
1980: 8	.00029764	.99970236
1980: 9	.07377398	.92622602
1980: 10	.33682124	.66317876
1980: 11	.23332468	.76667532
1980: 12	.00000676	.99999324
1981: 1	.11151247	.88848753
1981: 2	.24599801	.75400199
1981: 3	.01667675	.98332325
1981: 4	.00466780	.99533220
1981: 5	.00030478	.99969522
1981: 6	.01002016	.98997984
1981: 7	.06478360	.93521640
1981: 8	.04408075	.95591925
1981: 9	.15984890	.84015110
1981: 10	.27220229	.72779771
1981: 11	.42550669	.57449331
1981: 12	.44216846	.55783154
1982: 1	.01997782	.98002218
1982: 2	.00022894	.99977106
1982: 3	.03346390	.96653610
1982: 4	.13518409	.86481591
1982: 5	.31898314	.68101686
1982: 6	.43297488	.56702512
1982: 7	.48854007	.51145993
1982: 8	.13145867	.86854133
1982: 9	.03644787	.96355213
1982: 10	.00190049	.99809951
1982: 11	.07169765	.92830235
1982: 12	.14438196	.85561804
1983: 1	.36621945	.63378055
1983: 2	.60536367	.39463633
1983: 3	.58091765	.41908235
1983: 4	.74042991	.25957009
1983: 5	.83831322	.16168678
1983: 6	.90559954	.09440046
1983: 7	.94663114	.05336886

Table 12
(continued)

Date	Prob1	Prob2
1983: 8	.95188885	.04811115
1983: 9	.96673157	.03326843
1983: 10	.97560320	.02439680
1983: 11	.97503949	.02496051
1983: 12	.97518629	.02481371
1984: 1	.98004213	.01995787
1984: 2	.98234945	.01765055
1984: 3	.98274643	.01725357
1984: 4	.98212988	.01787012
1984: 5	.98325996	.01674004
1984: 6	.98269599	.01730401
1984: 7	.95590445	.04409555
1984: 8	.96028345	.03971655
1984: 9	.97160834	.02839166
1984: 10	.96233036	.03766964
1984: 11	.95014983	.04985017
1984: 12	.96472732	.03527268
1985: 1	.94916002	.05083998
1985: 2	.95148088	.04851912
1985: 3	.96172411	.03827589
1985: 4	.97498479	.02501521
1985: 5	.97333659	.02666341
1985: 6	.84306216	.15693784
1985: 7	.90563154	.09436846
1985: 8	.93207679	.06792321
1985: 9	.96797703	.03202297
1985: 10	.96883174	.03116826
1985: 11	.98555376	.01444624
1985: 12	.98470743	.01529257

Table 13
Plotted Autocorrelations
Markov Model Residuals

Note:
'a' denotes the estimated autocorrelation;
'*' denotes plus or minus two std. deviations.

```
lag  ++++++++++++++++++++++++++++++++
  1  +       *      a      *        +
  2  +       *     a+      *        +
  3  +       *      a      *        +
  4  +       *    a +      *        +
  5  +       *      +    a *        +
  6  +       *   a  +      *        +
  7  +       *      +a     *        +
  8  +       *     a+      *        +
  9  +       *      +   a  *        +
 10  +       *   a  +      *        +
 11  +       *     a+      *        +
 12  +       *a     +      *        +
     ++++++++++++++++++++++++++++++++
```

Table 14
Maximum Likelihood Results
Fixed Coeff. Model

Dependent Variable: LDFM1
Observations: 156
Degrees of freedom: 150
Log Likelihood : 613.773775

Variable	Coefficient	Std. Error	t-Stat	P-Value
Constant	0.005833	0.000473	12.323530	0.000000
Ar1	0.275296	0.065828	4.182031	0.000041
Ar2	-0.112782	0.088784	-1.270290	0.205942
Ar3	0.106287	0.105734	1.005238	0.316396
Ar4	-0.192542	0.066206	-2.908248	0.004180
Std.Err.Eqtn.	0.004732	0.000204	23.230852	0.000000

Computation Time: 3 minutes 39.21 seconds Iterations: 21

APPENDIX III

FIGURES

All figures discussed in the text are found in this appendix.

Figures 1–5 plot Ldfm1 and the N_t series.

Figures 6–13 plot the fitted coefficients described in Chapter VI.

Figure 14 plots the residuals of the four-rule switching model.

Figure 15 plots the residuals of the single-rule (OLS) model.

Figure 16 plots the estimated autocorrelations and partial autocorrelations for the fitted money residual series.

Figure 17 plots LDFM1 and shows the periods associated with the two states of the Markov time series model.

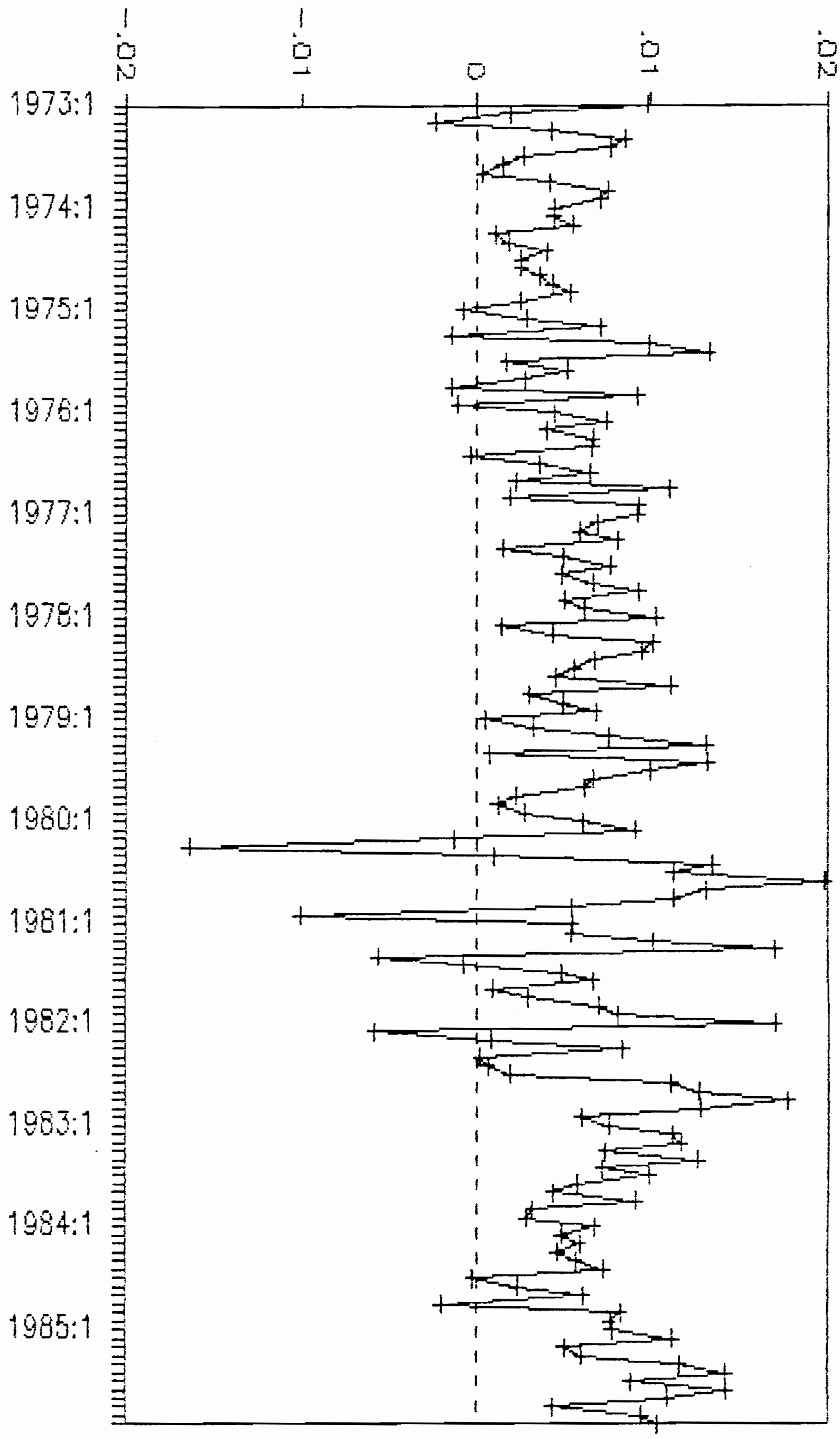

FIGURE 1

LDFM1

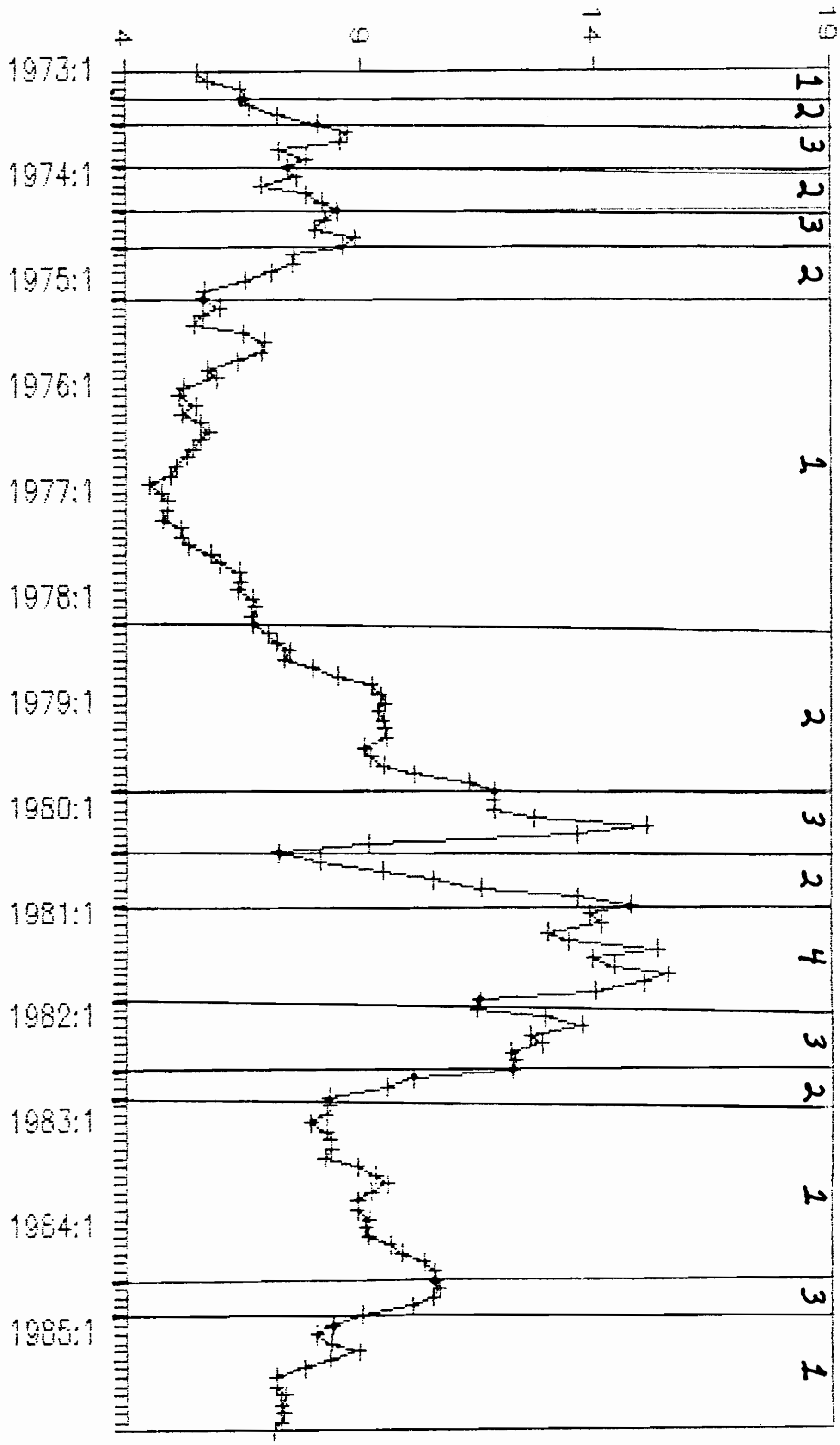

FIGURE 2

TBILL RATE AND MONETARY REGIMES

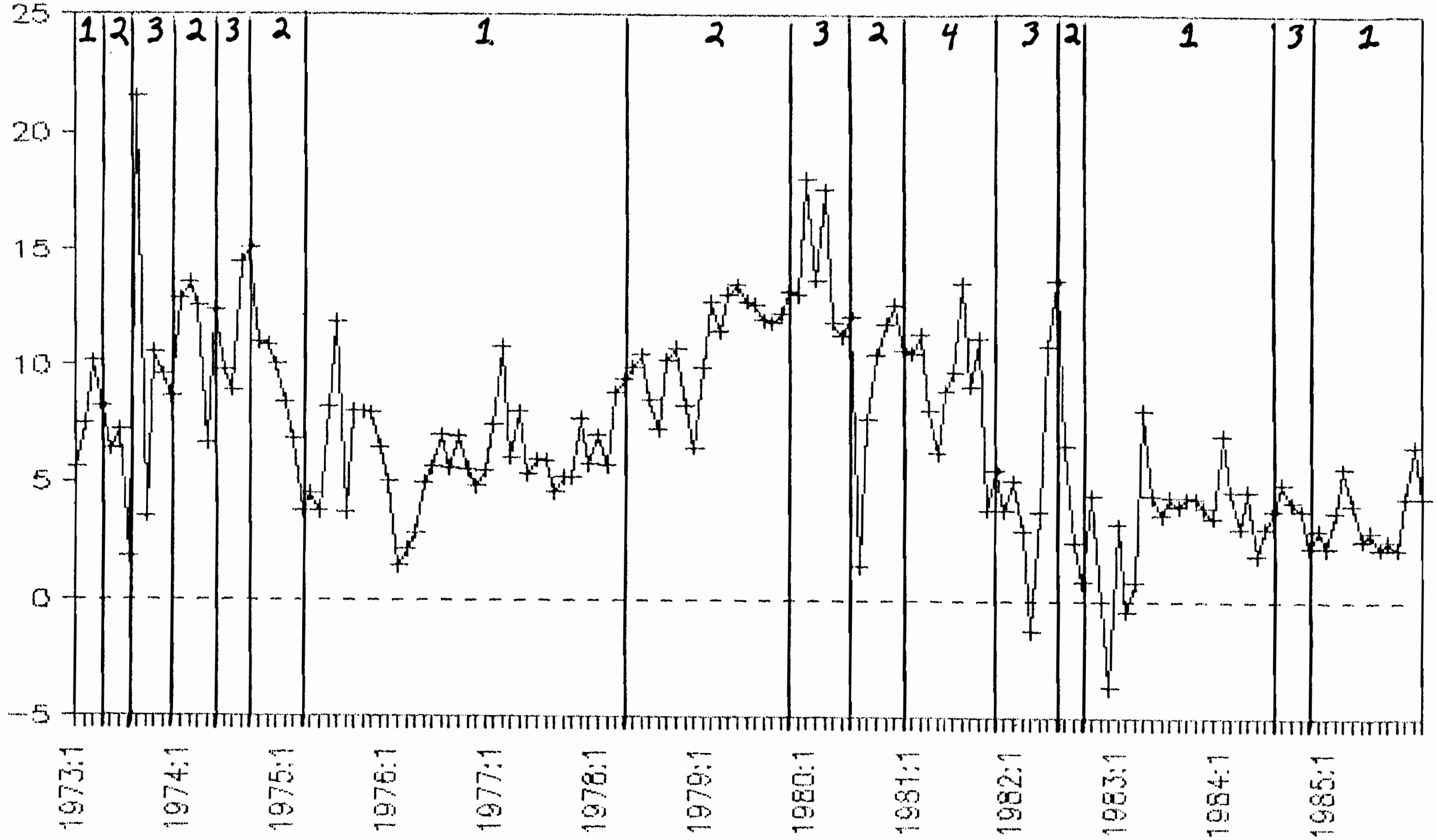

FIGURE 3

INFLATION RATE AND MONETARY REGIMES

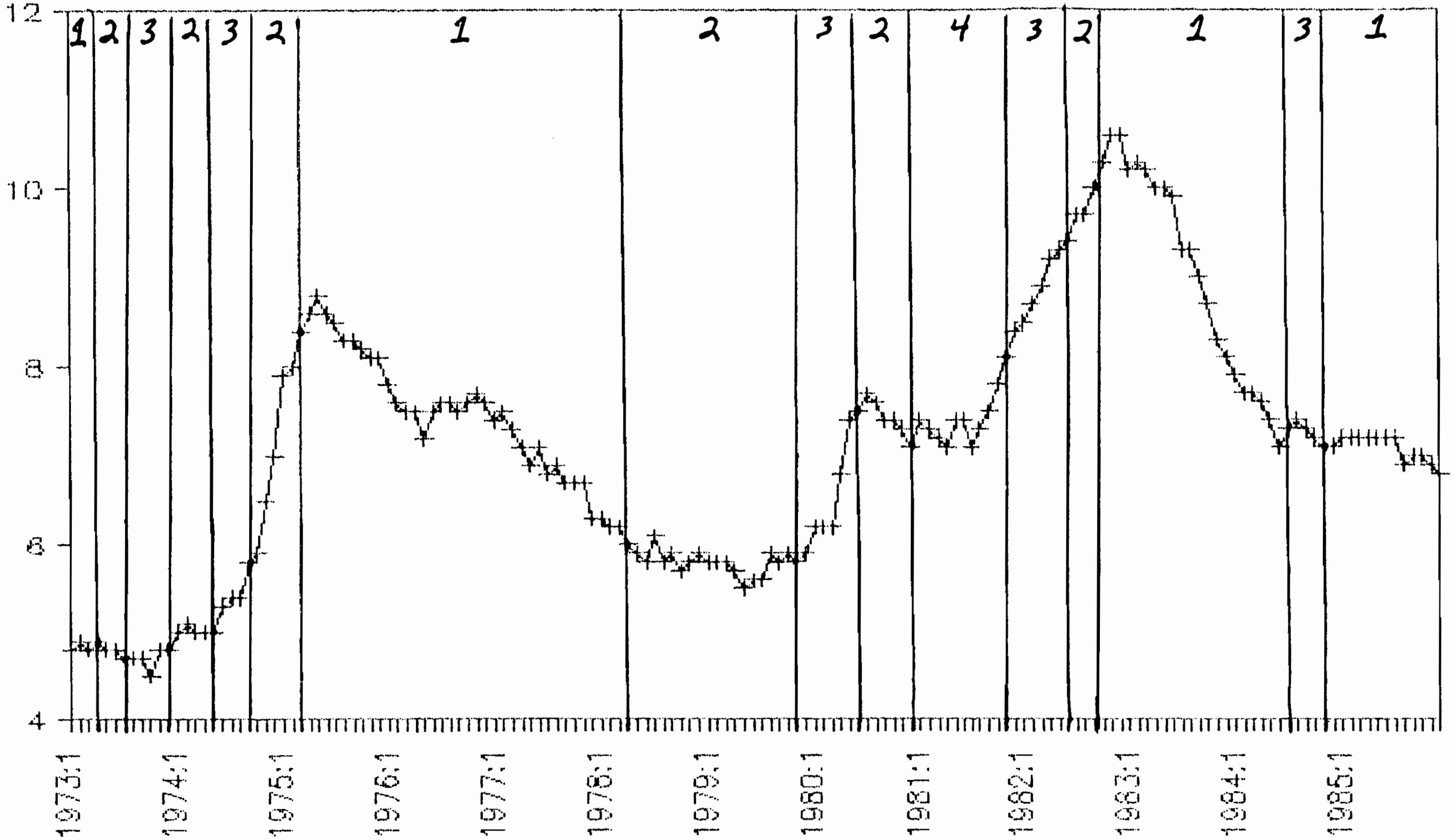

FIGURE 4

UNEMPLOYMENT RATE AND MONETARY REGIMES

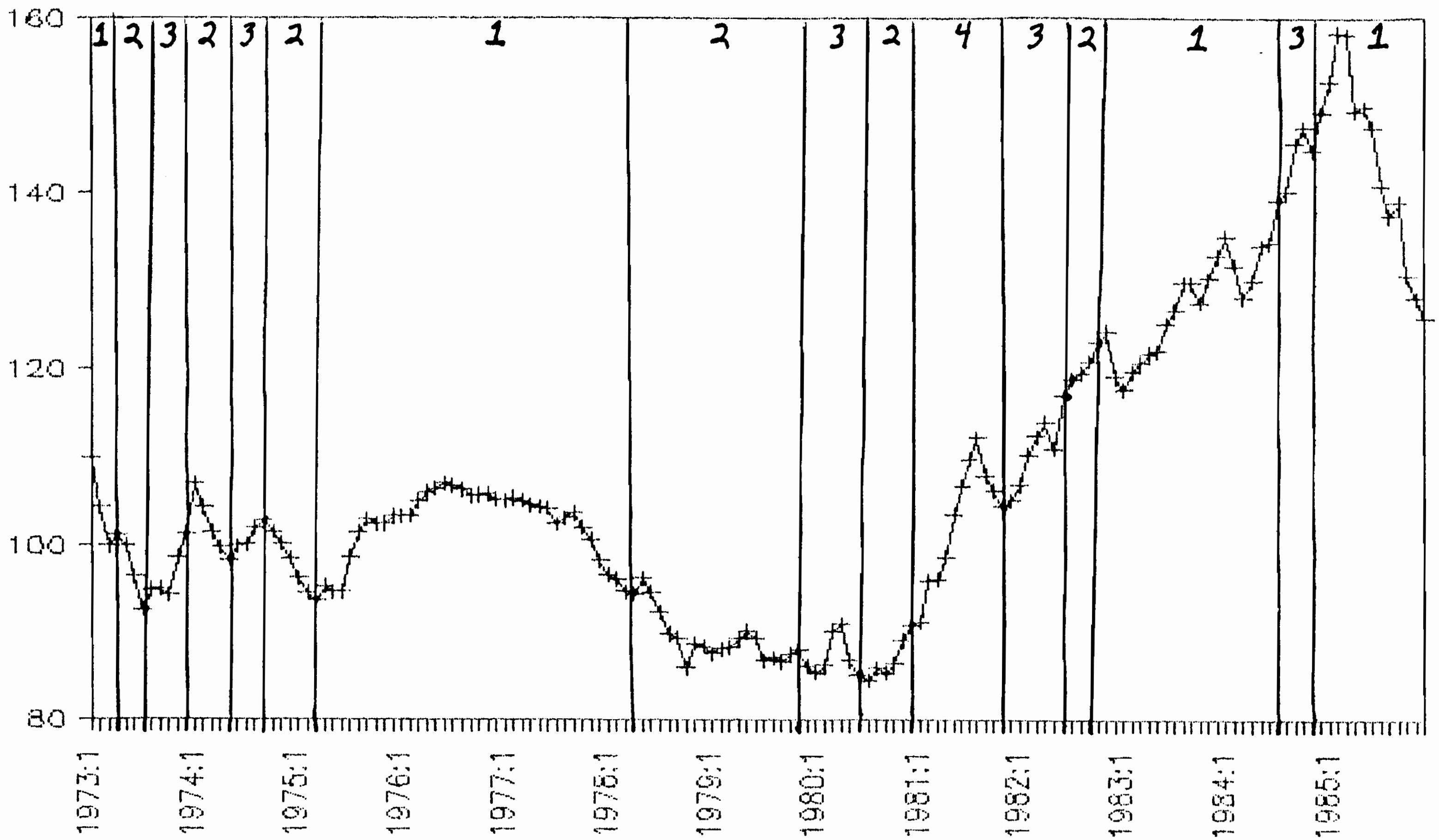

FIGURE 5

EXCHANGE RATE AND MONETARY REGIMES

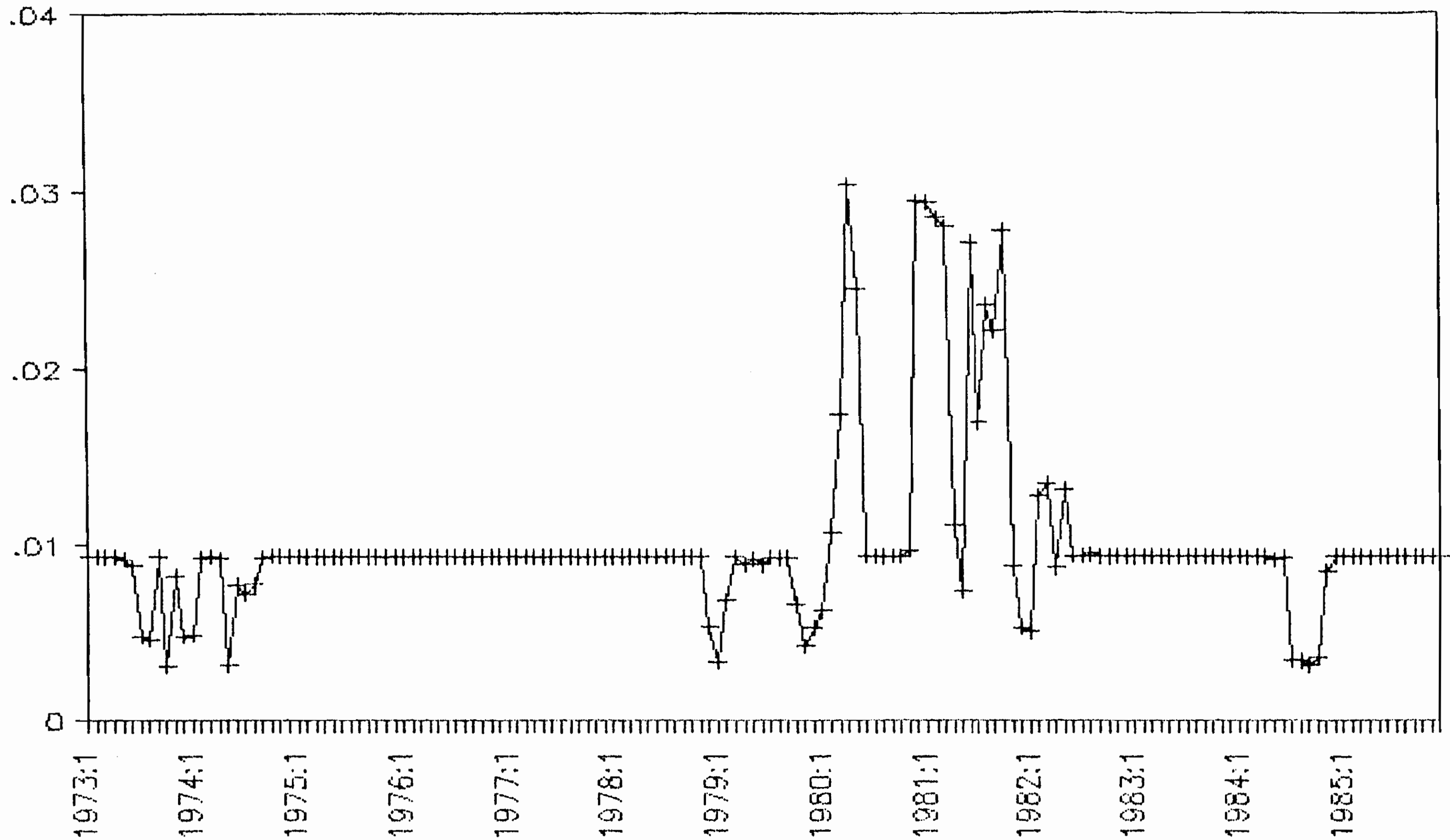

FIGURE 6

WEIGHTED CONSTANT COEFFICIENT

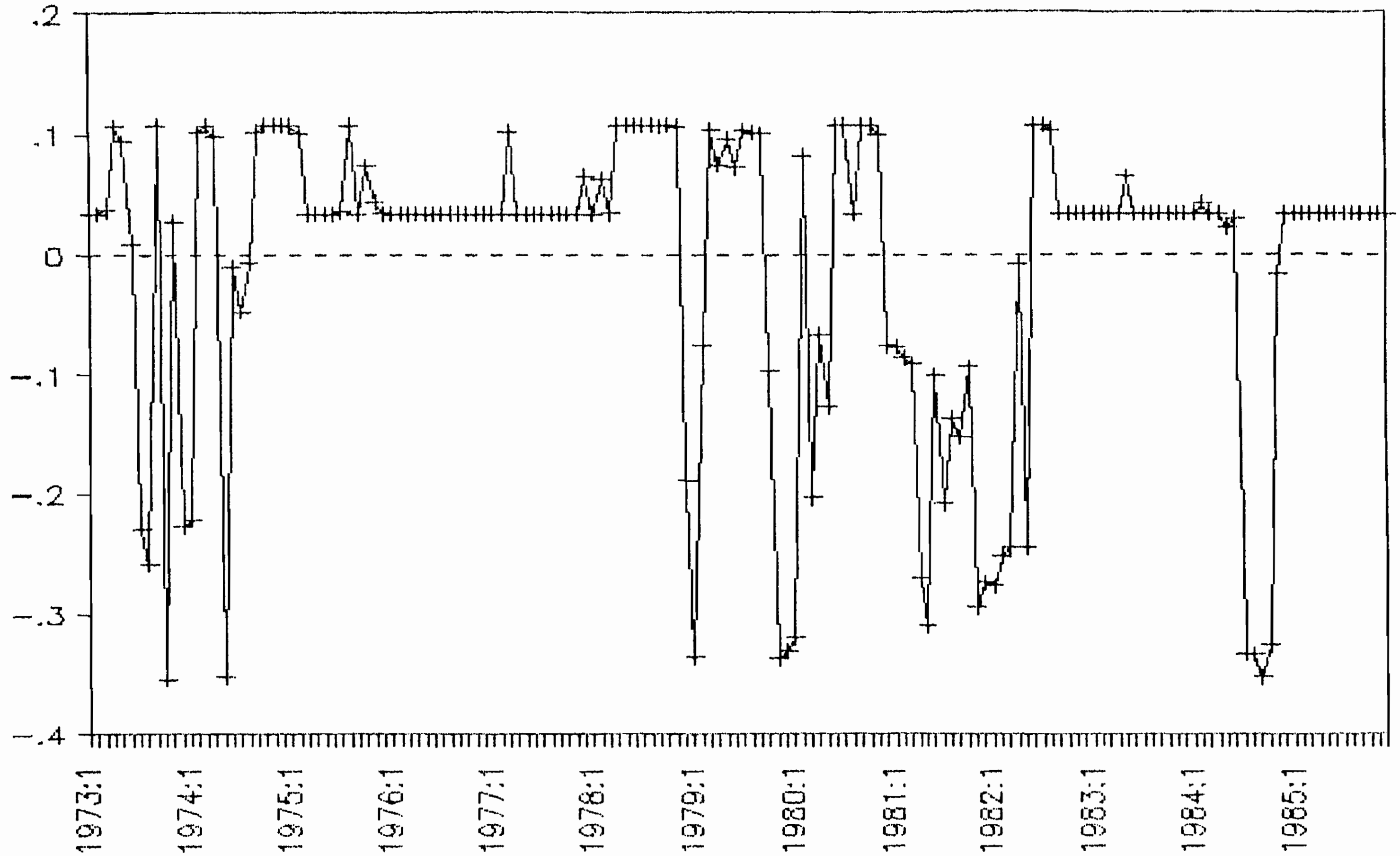

FIGURE 7

WEIGHTED COEFFICIENT ON LAGGED LDFM1

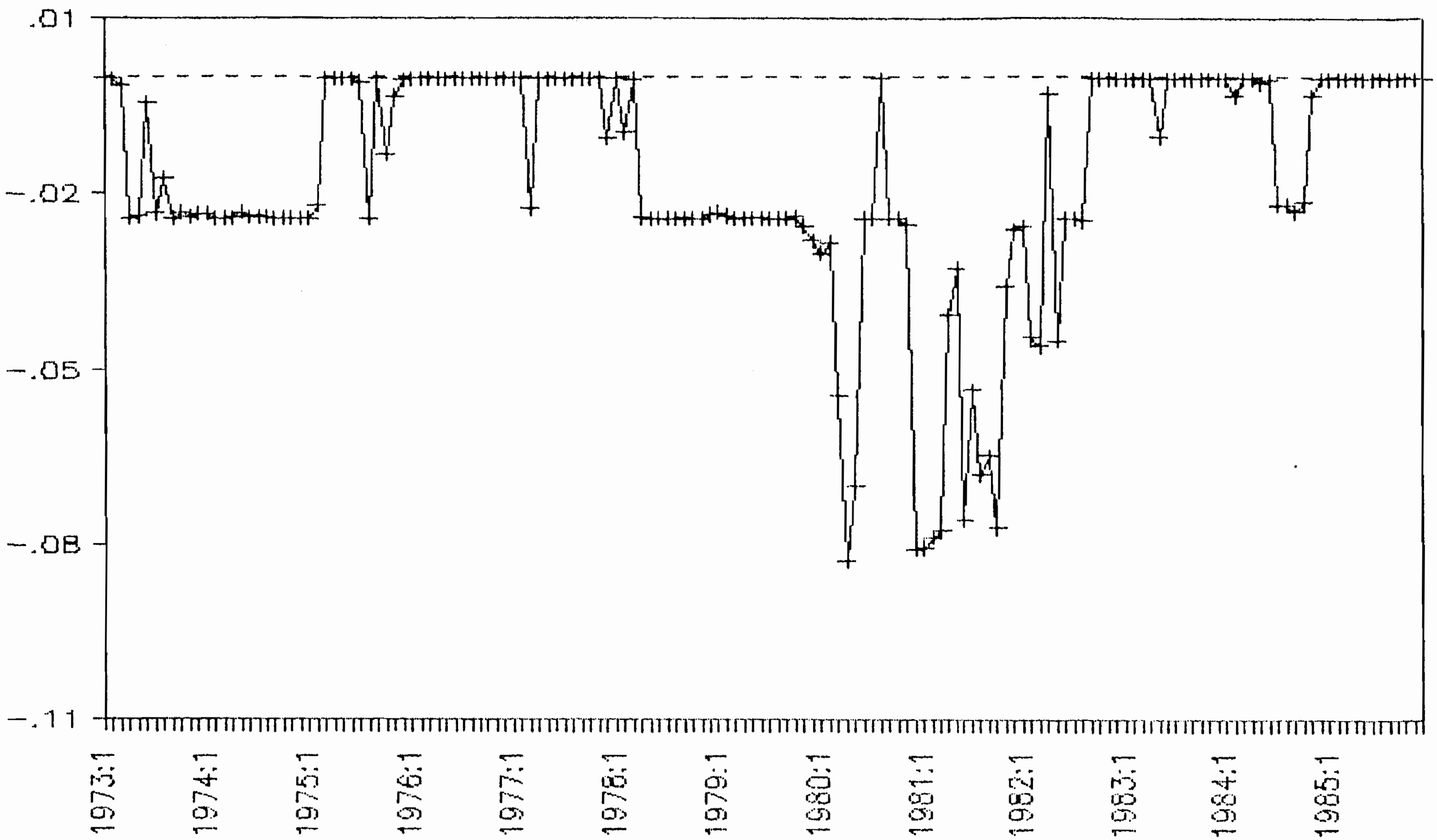

FIGURE 8

WEIGHTED COEFFICIENT ON LDTBILL

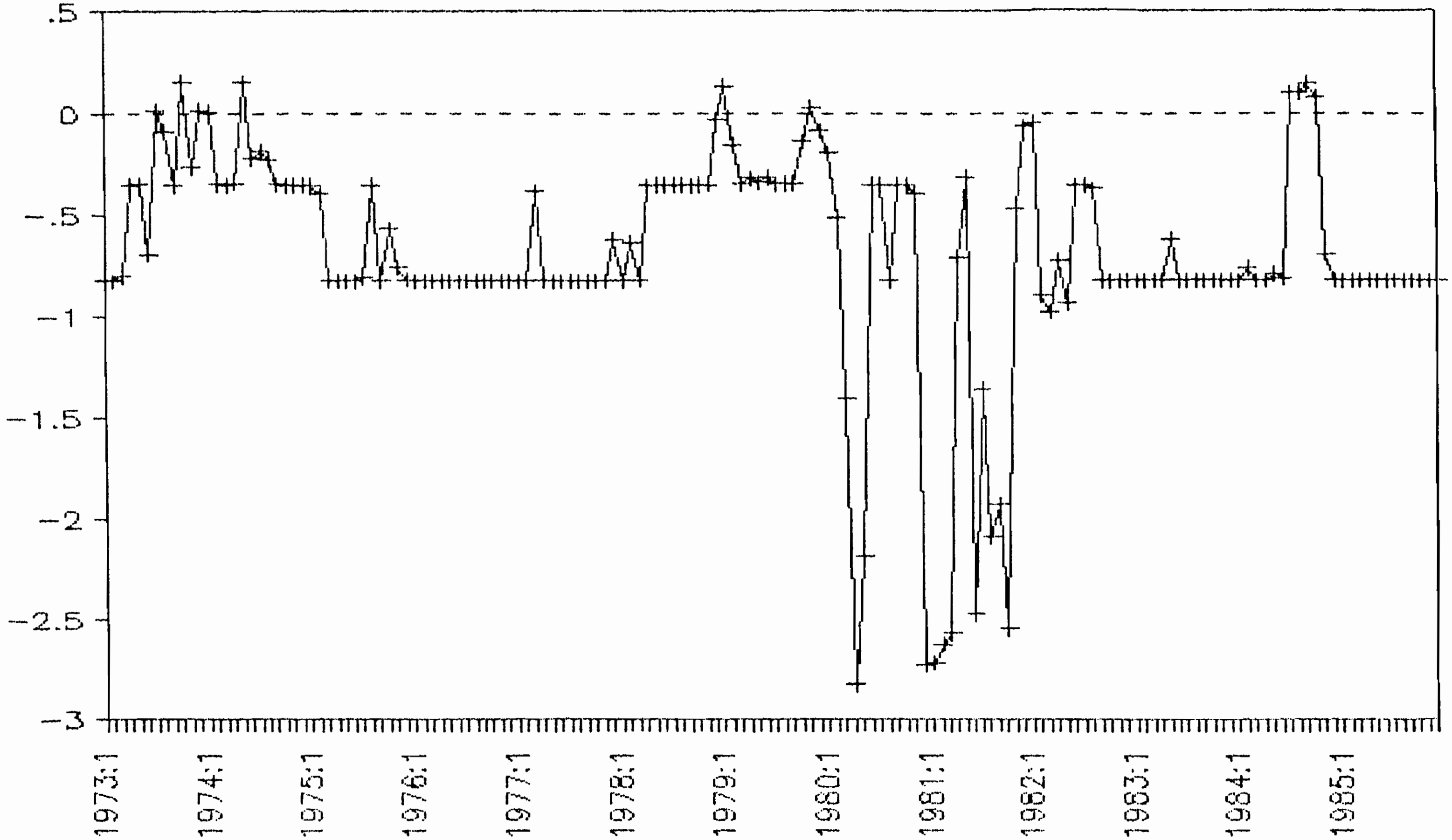

FIGURE 9

WEIGHTED COEFFICIENT ON LDCPI

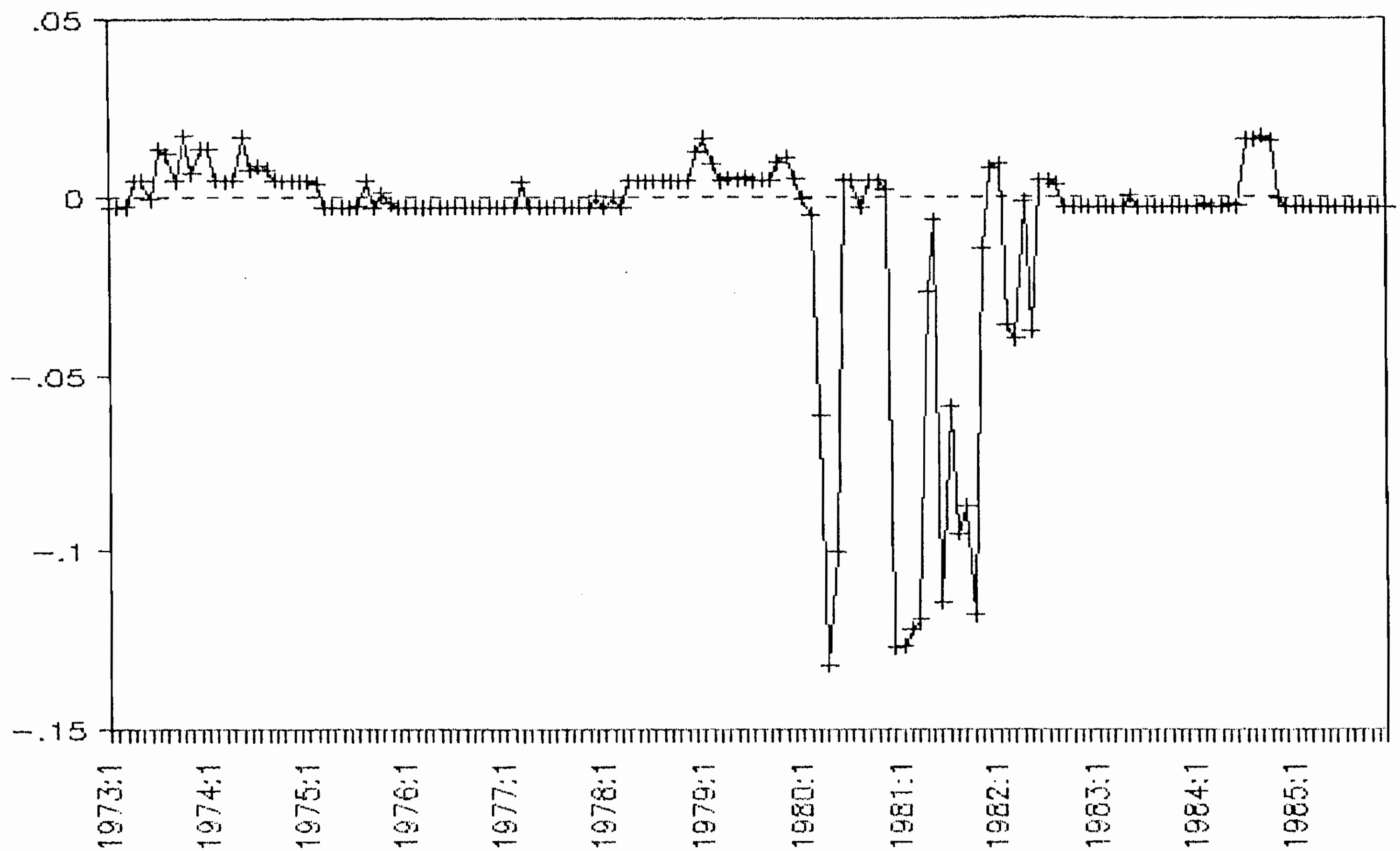

FIGURE 10

WEIGHTED COEFFICIENT ON LDUNEMP

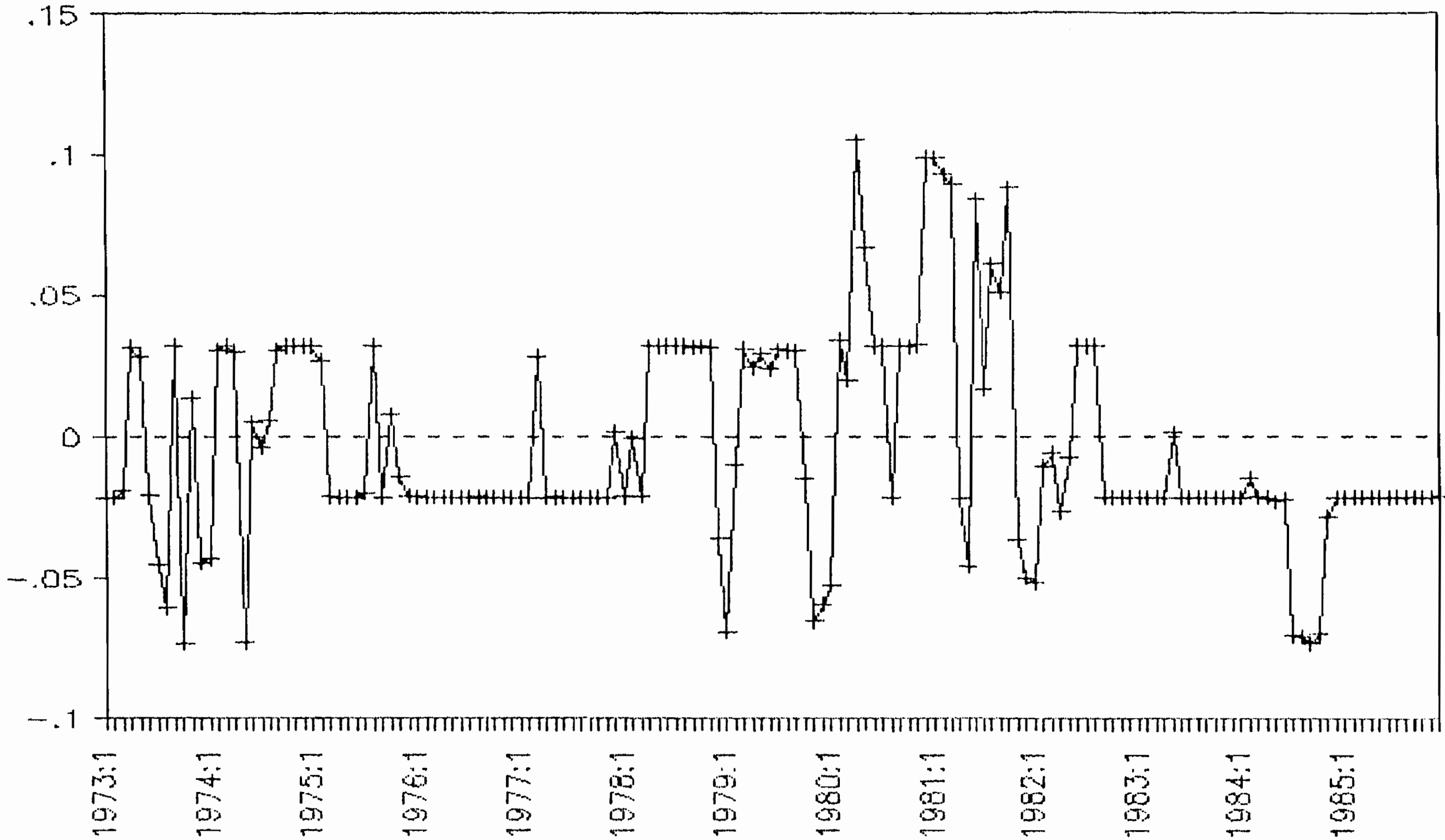

FIGURE 11

WEIGHTED COEFFICIENT ON LDEXVUS

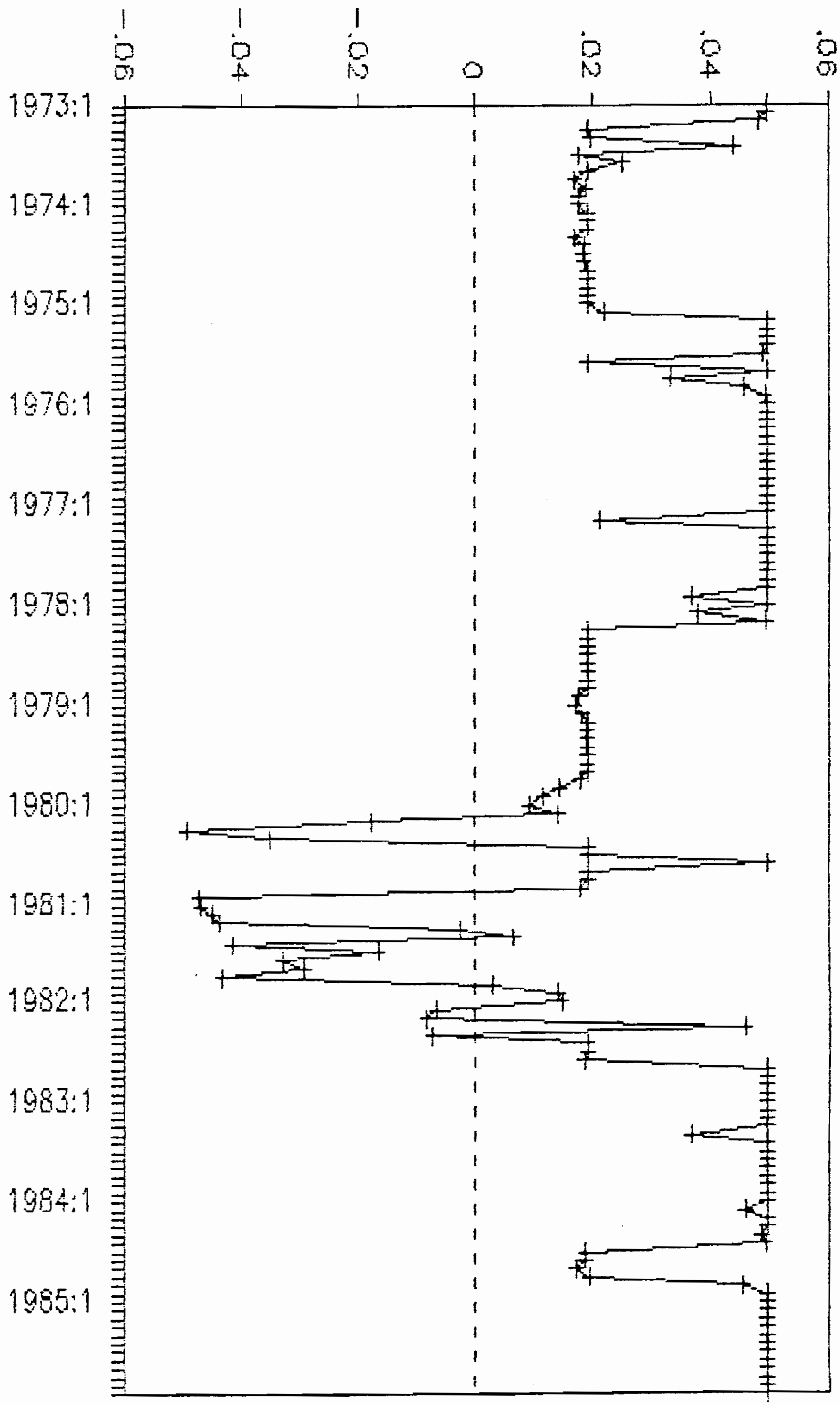

FIGURE 12

WEIGHTED COEFFICIENT ON LDFSP

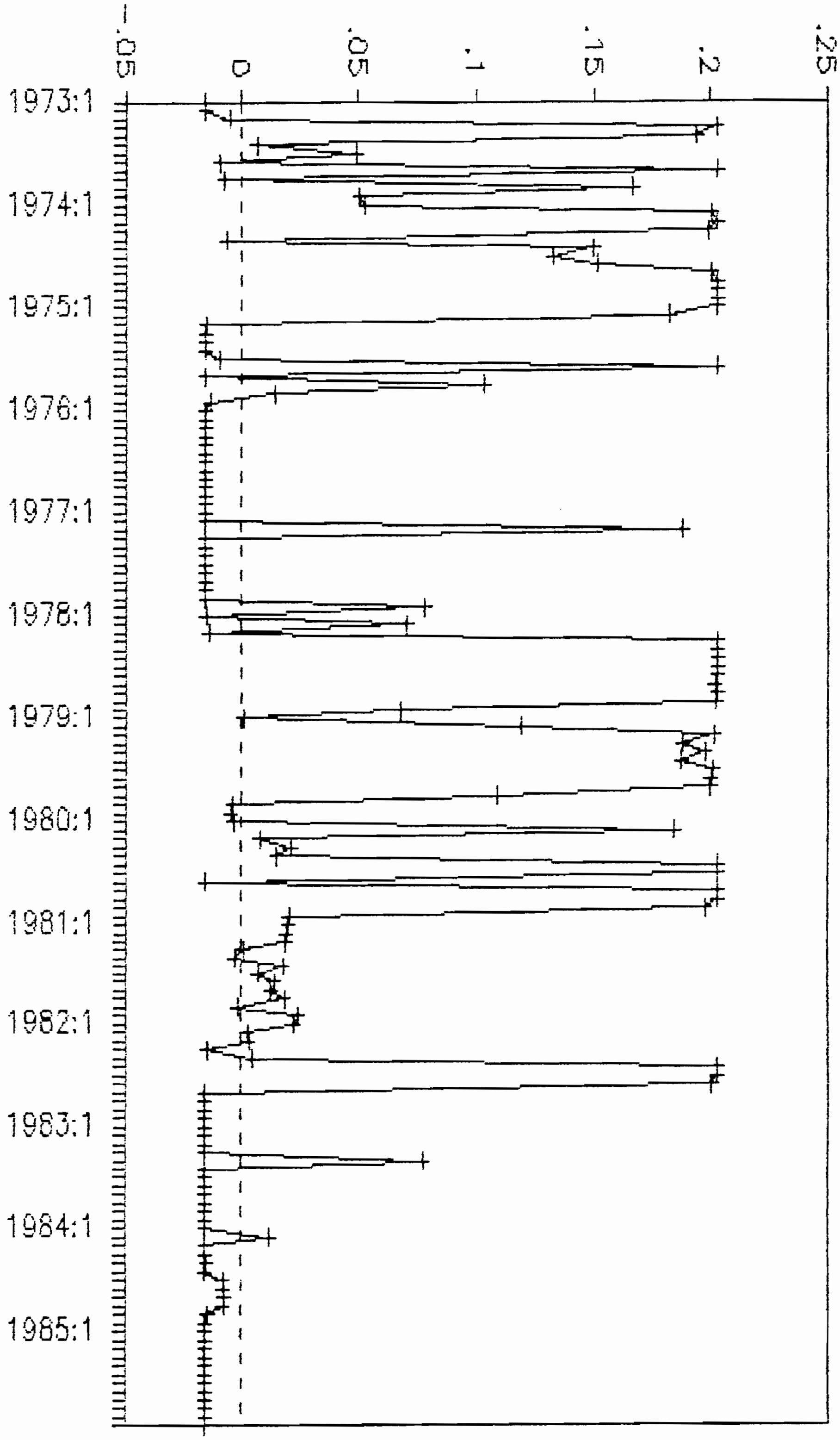

FIGURE 13

WEIGHTED COEFFICIENT ON LDIP

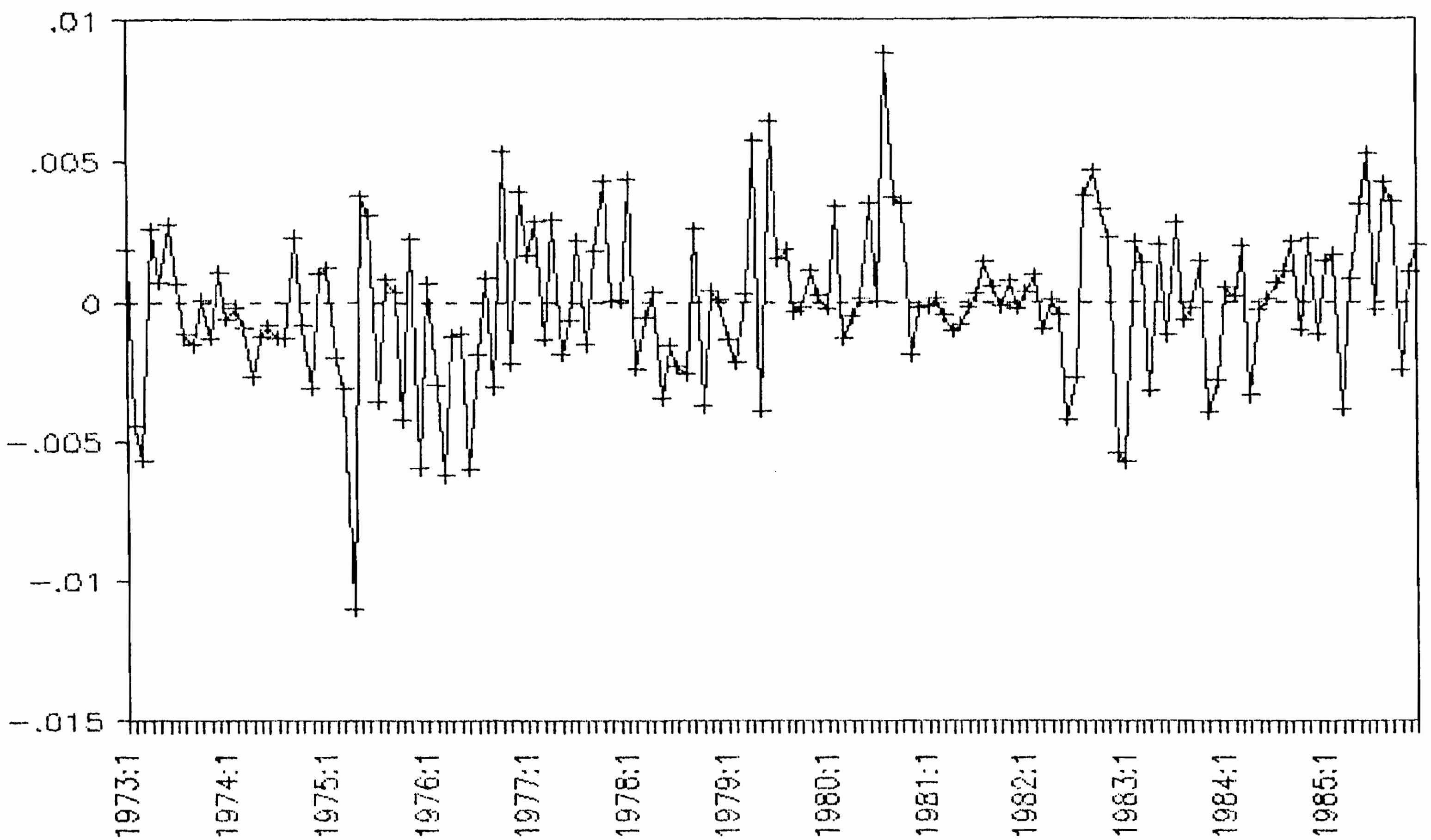

FIGURE 14

RESIDUALS FROM FOUR-RULE SWITCHING MODEL

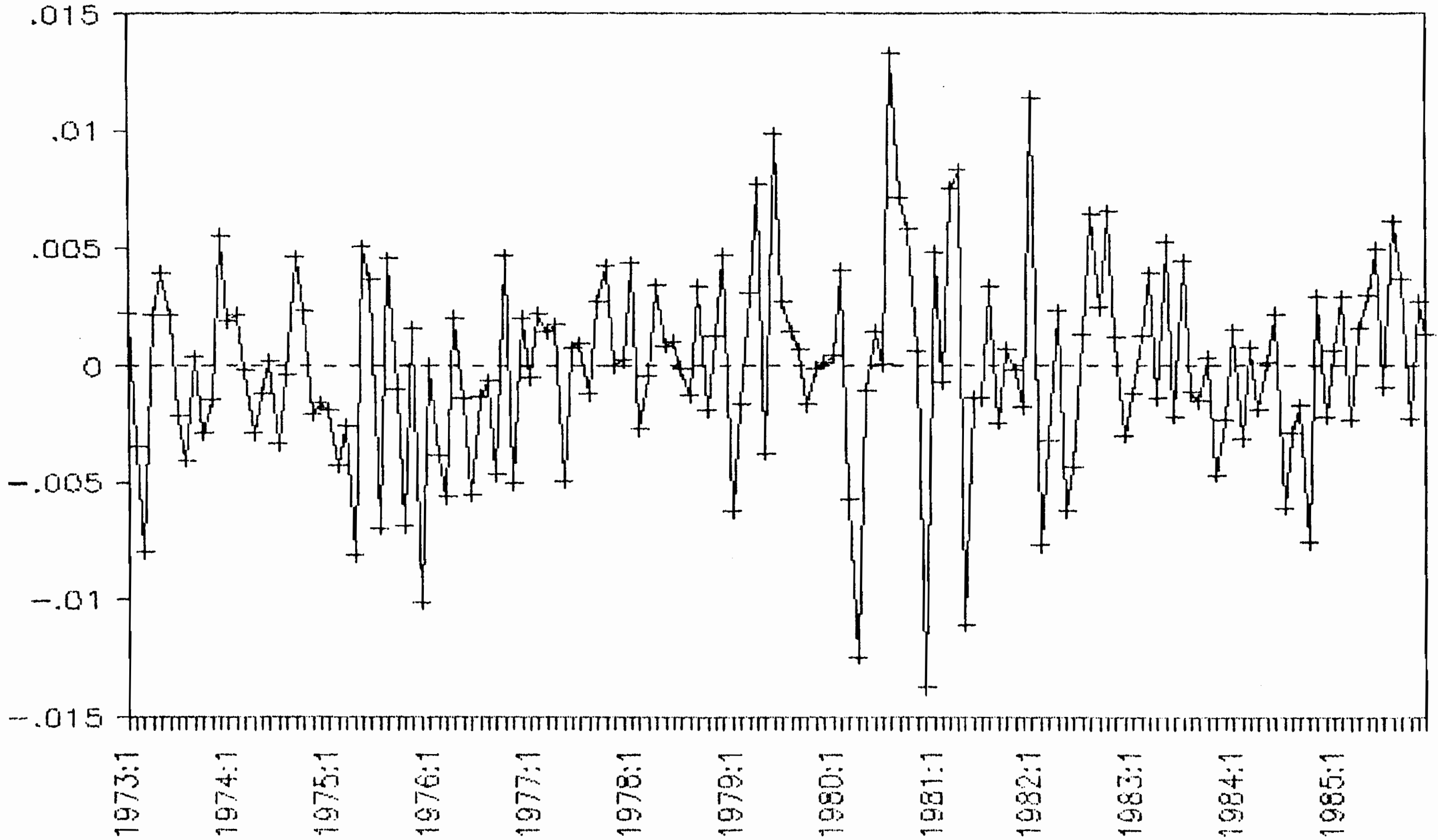

FIGURE 15

RESIDUALS FROM OLS MODEL

Figure 16

Plotted autocorrelations for four rule reaction function residuals.
'a' denotes the autocorrelation estimate.
'*' denotes two std. errors of the autocorrelation estimates:
'*' = 2/sqrt(T).

Autocorrelations

```
lag  ++++++++++++++++++++++++++++++++
 1   +       *      a      *        +
 2   +       *      + a    *        +
 3   +       *      +   a  *        +
 4   +       *    a +      *        +
 5   +       *      +a     *        +
 6   +       *      +    a *        +
 7   +       *    a +      *        +
 8   +       *      +   a  *        +
 9   +       *     a+      *        +
10   +       *   a  +      *        +
     ++++++++++++++++++++++++++++++++
```

Plotted partial autocorr. for four rule reaction function residuals.
'p' denotes the partial autocorrelation estimates.
'*' denotes two std. errors of the partial autocorrelations:
'*' = 2/sqrt(T).

Partial Autocorrelations

```
lag  ++++++++++++++++++++++++++++++++
 1   +       *      p      *        +
 2   +       *      + p    *        +
 3   +       *      +   p  *        +
 4   +       *   p  +      *        +
 5   +       *      p      *        +
 6   +       *      +   p  *        +
 7   +       *    p +      *        +
 8   +       *      +  p   *        +
 9   +       *    p +      *        +
10   +       *    p +      *        +
     ++++++++++++++++++++++++++++++++
```

VITAE

Gary L. Shelley was born in Bristol, Virginia on September 10, 1961. He graduated from Gate City High School in June 1979 and entered Virginia Polytechnic Institute in the following Fall. He received a Bachelor of Science in Economics there in June 1983. In Fall 1984, he entered the graduate program in Economics at Virginia Polytechnic Institute and will be awarded the degree of Doctor of Philosophy in Economics in December 1991.

He was Visiting Professor of Economics at West Virginia University for the Fall 1989 to Spring 1990 academic year. He was employed as an Assistant Professor of Economics at Appalachian State University in Boone, North Carolina in August 1990 and continues to serve in this position.

Gary L. Shelley

Gary L. Shelley