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CAN THE FED CONTROL REAL INTEREST RATES?

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SUMMARY

Three hypotheses concerning the controllability of rationally expected real interest rates are examined here. These hypotheses, which are suggested by recent literature, assert in different senses that the stochastic properties of expected real interest rates are independent of the Fed policy rule. We discuss the meaning and implications of the hypotheses, and how they might be tested. Evaluation of the hypotheses is attempted by examination of the Fed's "quasi-controlled experiments," historical changes in policy regimes, Granger-Sims causality tests, Barro unanticipated money regressions, and other methods. Questions as to the relevance of any such methods are discussed.

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I. Introduction

One contribution that the recent literature on "rational expectations" in macroeconomic models [1/] has to make to the older literature on the neutrality of money is to suggest a definition of the real interest rate in a stochastic environment and to suggest senses in which it may or may not be controllable by the monetary authority (or "Fed"). The new definition takes the "rationally expected real rate of interest" as the nominal or "money" interest rate (as quoted in financial markets or perhaps as an after tax interest rate) minus the optimally forecasted inflation rate. The senses in which it may or may not be controlled are described in terms of the nature of influence of the chosen parameters of the Fed policy rule on the stochastic properties (and relation to other variables) of the real rate so defined.

There are at least three distinct hypotheses concerning the Fed's influence over rationally expected real interest rates that seem to be suggested in recent discussions of monetary policy. We will give a brief statement of them here subject to clarification below. We will disregard at this point whether we wish to use an "after tax real rate". It is assumed throughout that Fed policy takes the form only of open market operations and that the interest rate is a short-term one. In order of decreasing stringency and testability, these nested hypotheses are:

Hypothesis 1 The form the Fed policy rule takes, whether deterministic or random, has no effect on the behavior of rationally expected real interest rates. That is, the Fed has no ability to shock rationally expected real interest rates at all in the short-run or long-run. This hypothesis has apparently never been asserted outright in the published literature but does seem implicit in many discussions. The hypothesis seems to be suggested by those who would try to explain interest rates in terms of inflationary expectations without apparent regard to the form monetary policy has taken. Fama, in his well known article on interest rates as predictors of inflation [1975] seems to suggest this hypothesis when he extends his hypothesis that one month real rates are constant to periods when the Fed apparently caused a "credit crunch", but he also at another point appears to explicitly deny that the Fed has no influence at all over real interest rates. 2/

Hypothesis 2 The Fed can shock rationally expected real interest rates, but only by taking policy actions other than the actions the public supposes they are taking. That is, if Fed policy on a particular day is known by the public on that day, it will have no effect on real rates.

Hypothesis 2 has some important implications. First, it implies that the Fed's ability to affect real interest rates relies essentially on secrecy. If the Fed opened up all of its internal discussion to public scrutiny without time lag, it would then lose any ability to affect real interest rates. Secondly, the hypotheses implies that even if the Fed is allowed to maintain secrecy, then still the systematic (i.e., non-random) part of its policy rule is without effect on real interest rates. That is, if the Fed attempts consistently to pursue any "sensible" or "purposeful" policy then its policy behavior will bear some consistent relation to business conditions, and will become predictable by economic agents outside the Fed. This assumes that the Fed has no secrets about business conditions, i.e., does not have any "information advantage" over the public.

Hypothesis 2 would appear to be suggested by many models which incorporate the Lucas-Sargent-Wallace aggregate supply relation (see, for example, Lucas [1973]), or variations on it and is specifically an implication of the macroeconomic model of Sargent and Wallace [1975].

Hypothesis 3 Any policy action by the Fed which is known by the public sufficiently far in advance will have no effect on rationally expected real interest rates. That is, we could in principle identify a "policy effectiveness interval" which might be as short as a few days or as long as many years. Any aspect of the Fed policy rule which relates only to information known earlier by this time interval will have no effect on the behavior of real interest rates.

The implications of hypothesis 3 depend on the length of the policy effectiveness interval. If the interval is years long, then the Fed may have substantial scope for systematic countercyclical monetary policy. Since the business "cycle" is not rigidly periodic it cannot be forecasted years in advance, and so even if the Fed policy rule follows a consistent or systematic relation to business conditions the public still will not have enough advance notice of the policy to react in such a way that real rates become uncontrollable. On the other hand, if the interval is very short then there may not be an important difference between hypothesis 3 and hypothesis 2. We will speak of this hypothesis as implying generally a policy effectiveness interval of, say, at least a number of months, but less than a number of years.

Hypothesis 3 seems to be suggested in many discussions. It is specifically a consequence of a model by Phelps and Taylor [1977] and would appear to be implied (though not explicitly in his model) by Fischer [1977]. These models connected the policy effectiveness interval with the length of time prices are rigid (Phelps and Taylor) or the length of time labor contracts run (Fischer). [3/]

All of our hypotheses are meant to characterize economies in "expectations equilibria", and in the literature that suggested them, "rational expectations equilibria". By an expectations equilibrium we mean merely a situation in which economic agents have unchanging subjective probability distributions for all stochastic variables in the economy. If this equilibrium is rational, these subjective distributions are correct. In such an equilibrium, then, economic agents have a correct understanding, to the extent that it will ever be understandable, of the Fed policy rule. What economic agents do not understand is represented as a stochastic term with known properties. Our hypotheses 2 and 3 concern comparative expectations equilibria, i.e., what changes in the behavior of economic variables will occur when the parameters of the policy rule are changed after the public fully appreciates the systematic nature of the change. In understanding hypotheses 2 or 3, it is particularly important to bear this in mind. If the Fed changes its policy rule (e.g., changes the way the money growth rate responds to unemployment) then there will no doubt be a transition period before a new rational expectations equilibrium is reached. 4/ The length of this transition period is not to be confused with the policy effectiveness interval.

These hypotheses would seem in principle to be subject to some form of empirical verification. However, the concepts of a "rationally expected real interest rate" and of a "Federal Reserve Policy Rule" and changes thereof are sufficiently slippery, as we shall discuss in Section II of this paper, that it is difficult to bring empirical evidence to bear on any of these hypotheses. It is perhaps for this reason that the literature relating to these hypotheses is almost exclusively theoretical. Empirical literature on the real interest rate (e.g., the Fama [1975] article mentioned above), while perhaps relevant to our evaluation of these hypotheses, does not explicitly consider them.

At the same time, there are some who have asserted, based on their observations of real world phonomena, that certain of these hypotheses are highly "implausible". It is apparently a useful exercise, therefore, to discuss how empirical evidence (qualitative as well as quantitative) might be brought to bear on them, if at all.

Our purpose in this paper is a) to discuss the definitions of "rationally expected real interest rates", and "Fed policy rule" and the meaning of the three hypotheses described above, b) to discuss the kind of subjective beliefs that must be added before these hypotheses have any testable implications, and c) to look at the data and empirical literature in monetary economics to see if there are any clues as to the plausibility of the hypotheses when they are given "reasonable" interpretations.

Some will perhaps argue that the abstract models that yielded these hypotheses are not to be taken literally, that they are intended as abstract possibilities that suggest a change in our methods of monetary policy evaluation. Nonetheless, people have applied them to discussions of historical experience and will no doubt be inclined to do so in the future. We think, then, that it is not premature to discuss whether these hypotheses might be considered useful in understanding historical experience. Needless to say, our examination of these hypotheses should not be interpreted as an evaluation of the contribution to the history of economic thought of the abstract models that gave rise to them.

II. Definition and Measurement of Real Interest Rates and Fed Policy Rule

II. 1 The Real Rate of Interest

A number of different definitions have been applied to the term "real interest rate". For simplicity, we will at this point disregard tax considerations in defining them.

First, the m-period real interest rate at time t has been defined as the money or "nominal" interest rate (the usual rate quoted at time t in financial markets) minus the actual inflation rate from time t to time t+m. [5/] Since the inflation rate is not known with certainty, the real interest rate by this definition is not known at time t, and hence we will refer to this as the *ex post* real interest rate. By this definition the real interest rate is readily measured *ex post*, at least insofar as inflation can be measured.

Second, the m-period real interest rate at time t has been defined as the nominal interest rate minus the average inflation rate forecast by professional forecasters as quoted in the news media. Readers of business periodicals are regularly supplied with inflation forecasts by the major consulting firms which specialize in macroeconomic forecasting. It has been argued that, realistically, no one in the public has any significant information advantage over these professional forecasters and that it would seem rational to base decision making on these forecasts. These consensus forecasts, while not market determined, are the result of intense discussion in a sort of intellectual "marketplace", especially in more recent years. We will call this the *consensus* real interest rate. The consensus real interest rate is readily measured with a slight lag, which is a publication lag. Since inflation forecasts generally move slowly, this lag is generally not important, but is *potentially* important in some hypothetical circumstances.

Third, the m-period real interest rate at time t has been defined as the rate quoted at time t on an m-period index bond. An m-period index bond is a bond whose coupons or principal due at maturity at time t+m are guaranteed in *real* terms, i.e., they are escalated by a price index. We will call this the *market* real interest rate. The market real interest rate is readily measurable at time t, since it is a rate quoted on financial markets. Unfortunately, a market for such index bonds does not yet exist in the United States.

We will digress for a moment to consider whether the Fed might control the real interest rate by any of these definitions. The *ex post* real rate is obviously not fully controllable, since inflation cannot be fully forecasted. Clearly, however, the Fed can always control the consensus real interest rate as it desires (so long, at least, as this is consistent with a positive nominal rate) if it is willing to accept the economic consequences of the control. It can choose a real interest rate, add to that the latest consensus inflation forecast, and then "peg" the nominal rate at their sum. If we abstract from current institutional details, the owner of the "printing press" could announce that it stands ready to borrow and lend unlimited amounts at this nominal rate, and then no one would borrow from another person at a higher rate nor lend to another at a lower rate. If the Fed can print nominal bonds as well as money in unlimited amounts, there is no limit to its ability to do this (nor to repay the principal on the nominal bonds when they come due). However, one might question whether it is really of interest that the Fed can do this. If the Fed, in its control of consensus real interest rates, were to cause rapid economic changes then the publication lag might make the concensus forecast unimportant to economic decisions. Markets might not all clear, so that the inflation rate based on quoted prices might become less relevant to economic decision making. A hyperinflation might ensue if they tried to peg them too low or if they consistently followed certain policy rules which would ultimately cause money to be abandoned as the medium of exchange. A deflation might ensue if they tried to peg them too high which would cause nominal rates to hit zero, ending their latitude for control.

It would seem highly plausible *a priori* that at any moment of time there is non-zero range over which the Fed can influence consensus real interest rates. Efforts to peg such real interest rates do not create unlimited riskless profit opportunities. In contrast, suppose (to take a simple extreme example) the Fed tried to establish different borrowing and lending (nominal) rates, and offered to lend, say, at 3.00% and borrow at an an epsilon higher rate. It would thereby create an unlimited riskless profit opportunity. Individuals would borrow from the Fed and use the proceeds to lend to the Fed and would reap a profit with certainty. It is realistic to suppose that if the Fed really announced this, however small the epsilon, it would quickly find infinite supply of both lenders and borrowers. If the Fed announced, on the other hand, a reduction of the consensus real interest rate from 2%, say, to 1%, it seems hard to imagine that anything really dramatic would happen and historical experience appears to confirm this. The question, then, is how far and for how long it can reduce or raise the consensus real interest rate.

The Fed would seem to have the same sort of potential control over market real interest rates with one modification. It could announce a market real interest rate and offer to buy unlimited quantities of index bonds at this rate, but it cannot sell unlimited quantities of index bonds. While it can promise to deliver unlimited quantities of money in the future, it cannot promise to deliver unlimited quantities of real goods in the future. There are limits to the Fed's ability to command real resources through inflationary finance. Hence it would seem that the Fed could *depress* market real interest as it pleases, but there are limits to its ability to elevate them. A hyperinflation is of course a possible consequence of depressing the market real interest rates too far or for too long.

The m-period rationally expected real interest rate at time t, which is defined as the m-period nominal rate quoted at time t minus the optimal forecast of the inflation between time t and time t+m, is not so readily observed either ex ante or ex post. The rationally expected real rate of interest is not necessarily equal to the consensus real rate of interest or market real rate of interest. In fact, the rationally expected real rate of interest is undefined unless economic variables are stochastic processes whose random properties are given. Such a definition thus makes sense only when the Fed behavior itself can be described as a stochastic process or policy rule related to other economic variables. The question then is, can the Fed, in deciding on its policy rule, choose a rational expectations equilibrium which is characterized by a desired behavior of the rationally expected real interest rate?

Such a definition of the real rate of interest is inherently academic, and at the same time a rather elusive concept. It is academic because in a world which is enormously complex and constantly changing, there is no way to define an optimal forecast without some assertion of faith in a model of some sort. Economic agents clearly have diverse models and forecasts. We can estimate empirical forecasting equations, but these will differ depending on the structure we assume, the explanatory variables we include, and the sample period we choose. The concept is also elusive when applied to the present issue for a couple of reasons. First, monetary authorities do not think of themselves as outcomes of stochastic processes and tend to think of themselves as exercising free will. If they must be described in terms of a reaction function, it would be logical to ask whether they can even choose parameters of this function. Second, it is no longer possible to speak of the Fed as defining its policy rule as a function of an observed real interest rate or observed expected rate of inflation, since these depend on the policy rule. That is, the Fed cannot announce that it will buy and sell bonds at 2% plus the optimally forecasted rate of inflation, since it does not know what this will be once it makes the announcement. A rational expectations theorist might be able, given a complete model of the economy, to find an "inflationary expectation" as a function of observable variables predetermined at time t such that if the Fed pegs nominal rates at the desired real rate plus this inflationary expectation, then this inflationary expectation will be an optimal forecast of the resulting inflation. But it is not obvious that we know the model such that rational expectations theorists might be enabled to do this. It is also conceivable that no such rational expectations equilibrium at the desired real rate of interest exists, or that, even if it might exist, there may be no path of economic variables that makes a transition from the present equilibrium to the alternative equilibrium. It may be, for example, that an announced policy of pegging the real yield of an index bond may not cause the economy to converge on a rational expectations equilibrium at all, because the price level may explode to infinity.

In this sense, then, models in which indefinitely fixing market real yields at some announced function of state variables will result in unstable price behavior might be described as models in which the rationally expected real rate is absolutely uncontrollable.

Given the difficulties with the concept of a rationally expected real rate of interest, a practical control theorist might conclude that there is no point even in considering the concept. One might wish to define the structure of the economy in terms of observable variables. However, it may be the case that, as rational expectations theorists have argued, the true structure of the economy is not comprehensible unless such variables are included in our model.

II. 2 Tax Law and the Definitions of the Real Interest Rate

For an individual or corporation in marginal income or corporate profits tax bracket τ the after tax ex post real rate of interest is found by subtracting the inflation rate from $(1 - \tau)$ times the nominal rate. This is the rate of increase in real after-tax buying power. Definitions of consensus real rates and rationally expected real rates may also be put on after-tax basis by replacing the nominal rate in the definition by $(1 - \tau)$ times the nominal rate. Now, we have not a single after tax real interest rate but an array of such rates, one for each tax bracket.

It has been suggested that our hypotheses should refer not to the simple real interest rate but to the after tax real rate for some "representative" tax bracket, or for the corporate tax rate paid by large corporations. There is a sort of intuitive plausibility to this suggestion. Consider two individuals in the same tax bracket who wish to make a three-month loan between them. No net taxes are paid by the two of them considered together since the borrower deducts interest paid equal to the amount declared as income by the lender. In effect, the government refunds τ times the interest rate from the lender to the borrower. In the face of inflation, if the individuals wish to keep the amount of real resources transferred in the terms of the loan the same as without inflation, they need only mark up their nominal rate by the inflation rate times $1/(1-\tau)$.

If our tax system were neutral to inflation in other ways, and if all individuals paid the same marginal tax rate, then it would seem quite plausible that our hypotheses should refer to the after tax real rate. The problem is that our tax system is not neutral in other ways to inflation. If the borrower in our example above wishes to use the funds to purchase physical assets for speculative purposes, then he will not be happy with an arrangement which keeps his real after tax interest paid constant in the face of inflation, since he will be taxed on the inflation of the price of his investment. Indeed, with such short-term speculation for which gains are taxed as ordinary income, his profits after tax will remain constant in the face of inflation only if the simple (not after tax) real rate is kept constant. The lender may then also be indifferent between making the loan and investing in the physical asset himself. On the other hand, if the borrower wishes to spend the money on a vacation, (and the lender views the opportunity cost of the loan as a vacation foregone) then he may be happy with the constant after tax real rate, precisely since he is not taxed on the "psychic" income from an investment in a vacation and hence inflation does not affect him in the same way. It is clear, then, that inflation affects taxes of individuals in different circumstances in different ways, and so it is not likely that hypotheses of the form one through three above could be given a simple rationale in terms of any particular definition of the real interest rate.

One possible conclusion of our consideration of tax effects is that our empirical work really should concentrate on the period before World War II when income taxes were relatively negligible. Post-war monetary policy is not really "pure" monetary policy since it affects real taxes. If we are interested in the ability of "pure" monetary policy to affect real interest rates, then we had best confine our attention to the period when such policy was practiced. Our approach here is instead to consider both periods in terms of the simple real interest rate even though for the post-war period the hypotheses may be of less interest.

II. 3 The Federal Reserve Policy Rule and Hypothesis Testing

We will suppose first that all relevant possible Federal Reserve Policy Rules can be summarized and indexed in terms of a parameter vector β in the form:

$$f(r_t, M_t, \beta, I_t, \phi_t) = 0 \qquad (1)$$

where r_t is the interest rate, M_t is the log of high-powered money, I_t is a vector of state variables or information at time t which characterizes the economy before the Fed acts at time t and is known to the public as well as the Fed, and ϕ_t is an innovation in Fed policy which is unforecastable by the public, i.e., is independent of the state vector I_t. We have written the function in implicit form to allow for both interest rate rules, money stock rules or combination rules.

The Fed confronts a public demand for high powered money function which we will write as:

$$g(r_t, M_t, I_t, \beta, \gamma, \delta_t) = 0 \qquad (2)$$

where γ is a vector of parameters and δ_t is a vector of innovations in public behavior. Public behavior depends on β through their reaction to the Fed policy rule. Equation (2) is a reduced form equation for the rest of the macroeconomic model, taking either r_t or m_t as exogenous.

Equations (1) and (2) represent a two equation model in two unknowns r_t and M_t. The solution to the model, or reduced form is:

$$r_t = h_1 (\beta, I_t, \phi_t, \gamma, \delta_t) \qquad (3)$$

$$M_t = h_2 (\beta, I_t, \phi_t, \gamma, \delta_t) \qquad (4)$$

Another reduced form equation from the macroeconomic model gives the price level:

$$P_t = h_3(\beta, I_t, \phi_t, \gamma, \delta_t) \tag{5}$$

and from this equation we can derive the expected rate of inflation $E_t(P_{t+1}-P_t)$ and hence the rationally expected real interest rate:

$$r_t - E_t(P_{t+1}-P_t) = h_4(\beta, I_t, \phi_t, \delta_t) \tag{6}$$

Hypotheses 2 and 3 concern the way this reduced form equation derived from the structural equations of our model depends on β.

One fundamental problem we face in explaining such models econometrically is finding identifying restrictions. One must know certain exogenous variables which we know shock equation (2) without shocking equation (1), and which may be used as instruments to estimate (1) consistently, and exogenous variables which we know shock equation (1) without shocking equation (2), and which may be used to estimate equation (2) consistently. The problem is that is is difficult to find <u>any</u> variable which we can be confident shocks one equation without shocking the other. When expectations are involved in the behavior which underlies (1) and (2), then <u>anything</u> which is publicly known might in principle affect both equations.

There is a literature on estimation of the demand for money and a smaller literature on the estimation of Fed reaction functions, which might be used to try to examine some of the hypotheses. However, we do not believe that estimates are trustworthy for this purpose. One reason is that this literature generally does not handle the simultaneous equations estimation problem well. When instrumental variables are used there is generally no discussion, let alone a convincing one, to justify the assumption that the exclusion restrictions and exogeneity assumptions are justified. This defect is compounded by the fact that with slow moving variables and short samples the small sample properties of the K-class estimators may differ widely from those predicted by the usual asymptotic sampling theory.

For the purpose of formulating policy, we need to know the model. For the purpose of evaluating the hypotheses noted in the introduction, however, it may not be necessary to estimate the model. If may instead by necessary, though, to find some change in β.

The first hypothesis noted in the introduction asserts that the structure of the economy is such that $r_t - E_t(P_{t+1} - P_t)$ is independent of either the Federal Reserve parameter vector β or the random vector ϕ_t. If we can find ϕ_t or a change in β, then the real rate should be uncorrelated with it.

The second hypothesis implies that if $\phi_t = 0$, i.e., the Fed is completely predictable, then $r_t - E_t(P_{t+1}) + E_t(P_t)$ is independent of β. Changes in the parameter β of the policy rule should not affect the random properties of the real rate. If ϕ_t is random, then this hypothesis has no unambiguous interpretation with a model of this generality. The division of Fed policy into "predictable" or "unpredictable" components might be achieved, for example, by positing a money stock rule of the form

$$M_t = f_2(I_t, \beta) + \phi_t \tag{7}$$

and then we might interpret the hypothesis to mean that the behavior of real interest rates is independent of β.

The third hypothesis, like the second, cannot be defined unambiguously until we decide how to divide Fed behavior into components which were and were not predictable in advance by the policy effectiveness interval. If we write:

$$m_t = f_3(I_{t-k}, \beta) + g_3(I_t, \phi_t) \qquad (7')$$

so that $f_3(I_{t-k}, \beta)$ is the component of Fed policy known in advance by the policy effectiveness interval k, then the hypotheses might be interpreted to imply that the interest rate is independent of β.

Unfortunately, although in casual discussions it is often assumed that the hypotheses are well defined, alternative interpretations are possible which would be represented by different versions of 7 or 7' and in turn different approaches to testing them. For example, we might break down money into <u>multiplicative</u> predictable and unpredictable components, we might allow f_3 in 7' to be multiplied by a function of I_t, or we might break down an <u>interest rate rule</u> into predictable and unpredictable components.

The only way that we can discuss direct verification of the second or third hypothesis cited in the introduction to this paper is to identify periods over which the Fed policy rule had stable repetitive nature and also identify when the transitions between these periods occured (i.e., where β changed). Our guide in identifying changes in the policy rule will be to look only for changes that were announced by the Fed and well understood by the public. It is inherently a highly subjective business to try to identify periods in which the Fed policy rule might be described as repetitive and when it changed. To evaluate hypothesis two or three based on statistical analysis, however, we have no alternative but to try to do so.

II. 4 Measures of Real Interest Rates

As noted above, it is impossible to measure the rationally expected real interest rate without a statement of faith in a model and if there are unknown parameters in the model an identification of a sample period of some length when the model held. If we take the above model, then, before looking at the data, we begin with prior distributions for the parameters β and γ, and for the parameters of the distributions of ϕ and δ. We might then in principle update the priors with the data over a period when the policy rule was stable to get a joint posterior distribution of β and γ and other parameters. This distribution might then be used to produce a predictive distribution for the *ex post* real rate conditional on historical data: $f(r_t - \Delta P_{t+1} | I_t)$, and we might define the rationally expected real rate as the expected value of $r_t - \Delta P_{t+1}$ from this predictive distribution.

The above approach suffers from the problem that it is difficult to describe our uncertainty regarding the nature and structure of the model. We thus seek a more parsimonious way to proceed.

An alternative is to seek a simple empirical forecasting relation by finding the optimal linear forecast of $r_t - \Delta P_{t+1}$ based on some small subset I_{o_t} of I_t which seems particularly likely to be important in determining the predictive distribution $f(r_t - \Delta P_{t+1}|I_t)$. For example, we might regress $r_t - \Delta P_{t+1}$ on its own lagged value to produce an autoregressive forecasting relation. We will call the fitted values of such a regression based on the subset of information and regression coefficients the optimal linear forecast, and denote it by $L(r_t - \Delta P_{t+1}|I_{o_t})$. Now one property of such optimal linear forecasts is that $L(r_t - \Delta P_{t+1}|I_{o_t}) = L(E(r_t - \Delta P_{t+1}|I_t)|I_{o_t})$; that is, the optimal linear forecast of the ex post real rate is the same as the optimal linear forecast of the true (unobserved) rationally expected real interest rate (see Shiller [1978]).

It is a property of optimal linear forecasts that the variance of the forecast is less than or equal to the variance of the variable forecasted (i.e., $R^2 \leq 1$). If we know the optimal linear forecast variance, we can put bounds on the variance of the true rationally expected real interest rate, i.e., its variance must lie between the variance of the optimal linear forecast and the variance of the ex post real rate.

The essential point for our purposes is the following: if we can establish that the Fed can control the optimal linear forecast of the ex post real rate in the sense of one of our hypotheses, e.g., that it can, by changing β, and without relying on unforeseen shocks ϕ_t, affect the random properties of the optimal linear forecast, then it can affect the random properties of the true unobserved rationally expected real interest rate. Since the projection of the optimal linear forecast on I_{o_t} is the same as the projection of the true rationally expected real interest rate on I_{o_t}, one cannot change the one without changing the other and hence one concludes that one must have changed at least the relationship of the rationally expected real interest rate with I_o.

III. Empirical Verification Hypotheses

III. 1 General Approach

In this section we will explore interpretations and tests of the three hypotheses described in section I along lines suggested in section II above.

In section III 2 below we consider whether the hypotheses are plausible in view of the observed behavior of nominal rates coupled with the fact that the precise timing and magnitude of Fed actions are probably exogenous and unforecastable. We also consider here the fact that the Fed apparently can (and has) pegged nominal rates, which means that there was a sharp reduction to zero in exogenous shocks to monetary policy at this time.

In section III 3 below we consider whether the history of the Federal Reserve System can be broken down into sub-periods in which the policy rule showed a distinctly different stochastic behavior. The sub-periods must be long enough that it makes sense to try to identify the policy rule from the data. We argue that there is some reason to divide the monetary history of the twentieth century into three long periods: the period from 1900 to 1913, before the Fed was founded, the period 1914 to 1950 of early monetary policy (which was unfortunately disrupted by two world wars and a major depression) and the period 1951 to the present when modern monetary policy was practiced.

In section III 4 below, we consider Granger-Sims causality tests between real interest rates and money growth rates, and Barro unanticipated money tests as ways of evaluating these hypotheses.

III. 2 Behavior of Nominal Interest Rates

Members of the Federal Reserve Board -- and of the Trading Desk at New York -- have the distinct impression that they can, whenever they wish, influence nominal interest rates in a downward direction by increasing high powered money and in an upward direction by decreasing high powered money. This impression is very strong because they have seen it happen with great reliability. Moreover, since they were involved in the decision relating to the conduct of monetary policy, they have a clear idea whether their policy might be considered caused by economic circumstances and to what extent their policy might be viewed as a controlled experiment. Certainly the precise timing of their policy is determined by their own choices and if interest rates immediately respond reliably when they do intervene, it is hard to question that they can control nominal interest rates in this manner.

If we accept, then, that when the Fed decides to intervene in the open market by increasing high powered money the nominal interest rate declines, it would appear that the Fed must have some influence over real interest rates, and hypothesis 1 must be wrong. We usually think that increasing high powered money is if anything a signal of higher inflation. It would seem implausible, then, that these lower interest rates are due to lower inflationary expectations. It is conceivable that exogenous increases in the money stock might be a sign of lower inflation over a certain time horizon if the parameters of our model were just right. But it seems inconceivable that such an explanation would reliably hold true for bonds of all maturities for the history of all monetary authorities for hundreds of years.

Even though the Fed knows it can impact the real interest rate at any moment in a desired direction, it does not follow that it can exert any systematic control over real interest rates, i.e., hypothesis 2 or 3 may still be valid. To see how this might be the case, we may hypothesize a demand for high powered money function of a form which is somewhat less general than expression

(2) above:

$$M_t = M_{t-1} + \mu(M^*_t - M_{t-1}) + \eta_t \qquad 0 < \mu \leq 1 \tag{8}$$

where $$M^*_t = P_t + m_1 Y_t - m_2 r_t - m_3(E_t(P_{t+1} - P_t)) + m_4 Z_t \tag{9}$$

and all coefficients m_1, m_2, m_3 and m_4 are greater than zero. η_t is an unforecastable error. Here we have assumed a simple stock adjustment model although more general adjustment models would not affect the basic conclusions. The desired log money stock M^*_t is a function of the log price level, P_t, a measure of aggregate economic activity Y_t, the nominal short interest rate r_t, the expected inflation rate and other exogenous real variables Z_t. Substituting (9) into (8) and using $r_t = \rho_t + E_t(P_{t+1} - P_t)$ we get:

$$M_t = (1-\mu)M_{t-1} + \mu P_t + \mu m_1 Y_t - \mu m_2 \rho_t - \mu(m_2+m_3)E_t(P_{t+1} - P_t) + \mu m_3 Z_t + \eta_t \tag{10}$$

Taking expectations conditional on information at time t and solving for $E_t P_t$ we get:

$$E_t P_t = (1-\lambda)E_t J_t + \lambda E_t P_{t+1} \tag{11}$$

where $$J_t \equiv \Delta M_t/\mu + M_{t-1} - m_1 Y_t + m_2 \rho_t - m_3 Z_t - \eta_t/\mu$$

$$\lambda = (m_2 + m_3) \;/\; (1 + m_2 + m_3) \qquad 0 < \lambda < 1$$

If we then solve this rational expectations equation and assume stable price behavior, i.e., a price level which does not diverge to infinity unless the money stock is increased to infinity as suggested in the rational expectations literature, or in this specific context by Sargent and Wallace [1975] we find:

$$E_tP_t = (1-\lambda)\sum_{i=0}^{\infty}\lambda^i E_t J_{t+i} \tag{12}$$

and

$$r_t = \rho_t + E_t(P_{t+1} - P_t) = \rho_t + (1-\lambda)\sum_{i=0}^{\infty}\lambda^i E_t(\Delta J_{t+i+1}) \tag{13}$$

The model thus implies that the price level, as well as the nominal interest rate, embodies optimal forecasts of ΔJ_{t+i}, $i = 0, 1, \ldots$ We can thus see how it is that the Fed may have the impression that it influences the real rate and could do so systematically when in fact it cannot. Suppose we hypothesize a money stock rule of the form (7) above. Although the Fed may not be aware of it, the public has divided its behavior into two components: a predictable and unpredictable component. The public has already formed anticipations of all future movements in the money stock based on information about Fed policy that has unfolded to that point in time. If the public anticipates a policy of greater increases in the money supply, then nominal interest rates will by (13) rise as soon as the public begins to collect information which enables it to anticipate this. If the Fed delays expanding the money stock longer than the public expected, then interest rates may rise further still, due to the effect on real interest rates of this "surprise" until the date when the Fed does intervene when interest rates may drop back to the level given by (13). If, on the other hand, the Fed increases the money growth rates sooner than the public expected, then interest rates may fall when they do this, and may rise back to the level given by (13) when the Fed is on target again.

Whenever the Fed has the sense that its actions are volitional, i.e., could not have been predicted by the market, it observes the customary negative relation between real rates and high powered money. The Fed knows these shocks are exogenous and thus knows it has influence over real rates. On the other hand, the Fed rarely observes the effect of its changes in its policy rule, and if it does not look deep into history, has no information on its systematic ability to control real interest rates.

This analysis does not necessarily suggest a scenario in which, as described for example by Friedman [1968], increases in high powered money cause a decline in interest rates for a certain interval of time (the "liquidity effect" period) followed by a rise in interest rates above its former level due to engendered inflationary expectations. Friedman's scenario might come about if unforeseen shocks constituted evidence that further money growth rates would be higher, in which case inflationary expectations would be immediately adjusted upward, and if temporary effects on real interest rates were sufficient to offset the rise in inflationary expectations.

The crucial behavioral relation that gives the result that the Fed has no systematic influence over real interest rates is embodied in expression (12) coupled with hypothesis 2 which implies this the real variables in J_t are not subject to systematic Fed control. Expression 12 then says that the price level incorporates all information currently available about future money supplies. Without this relation, the Fed must be able to control real rates or the price level must be explosive, even with stable monetary policy. Suppose, to illustrate, the Fed announces that the money stock today will be decreased by three percent below what the public had expected, but that all future money growth rates will be unchanged. By (12), and hypothesis 2, and assuming for simplicity that $\mu = m_3 = m_4 = 0$, the price level must drop immediately, and by (13) the nominal rate will be unchanged. It seems unlikely that the price level would drop immediately by 3%, however. If the price level is sluggish, can we retain hypothesis 2? To retain it would mean that the real money stock falls and hence, by the money demand equation (9), that the nominal rates r_t must increase. If the real rate is constant, this must imply that expected inflation will increase. If this expected inflation is rational, then it must be the case that actual inflation increases, at least on average. Thus, the price level tends to increase in the following period, rather than decrease, which throws the system further out of equilibrium. By the same reasoning the price level is expected to increase even faster the following period, and, by induction, must explode to infinity even with a stable money supply.

If we assume only hypothesis 3, then (12) still must hold but now we have lost the proposition that the future real rate and future real income terms in J_{t+i}, $i = 0, \ldots\infty$ are independent of the entire systematic component of monetary policy. Since our hypothesis then does not constrain these y and ρ terms in J, it says nothing about how the price level responds to current information about Fed policy, and so (12) has itself no content in this regard. Hypothesis 3 does imply that real variables are independent of information about monetary policy known earlier by the policy effectiveness interval. The price level, today, optimally incorporates all information about future monetary policy that was known then.

While this behavioral assumption in (12) may be plausible for prices of speculative commodities, this seems improbable for the aggregate price level judging from the way many prices are actually set. It is not just that prices are "sticky" or "sluggish" but that they are not set in anticipation of future monetary policy. It might not be too unreasonable to suppose that the prices of speculative commodities take into account a very simple, repetitive seasonal pattern in money growth rates. It is also conceivable that if the money stock has a simple predictable pattern over the business cycle then the prices of certain speculative commodities might in effect incorporate this information. But will wages be set in this way? Will the price of haircuts? It seems likely that at least some modification of equation (12) is called for to allow for other factors which help determine the aggregate price level, and this will then invalidate hypotheses 2 and 3.

One reason that (12) and our hypotheses seem implausible is that the public is certainly not consciously aware of it. News reports routinely ascribe movements in the stock market indices to new information, but changes in aggregate price indices, while a subject of great public interest, seem never to be ascribed to new information about future monetary policy. Hypothesis 2 requires that if the Fed announces a change in its long run target, the announcement itself (if credible, and not already discounted by the public) should have an immediate effect on the price level and on the nominal interest rate. Judging casually from the lack of public awareness of such an effect, we think that the effect is certainly not likely to be a very striking one.

Further evidence on the plausibility of (12) and (13) can be obtained by considering the effects of the Fed's announcing that interest rates will be pegged at a certain level. Before we consider this, we will point out that this has actually happened.

At the end of April 1942 the Federal Open Market Committee directed the twelve Federal Reserve Banks to purchase all Treasury bills offered at a discount rate of 3/8 of one per cent and in August directed the Federal Reserve Banks to give the seller an option to repurchase bills of the same maturity at the same rate. An ascending rate structure on government bonds was also pegged, peaking at 2.5% for the longest bonds. A demand for short-term bills persisted for a while with this structure, but as confidence grew that the Fed would continue to peg long rates at this level, evaporated. In July 1947, the Fed thus ended the peg on treasury bills. In December 1947 the Fed also lowered its buying price to near par on long-term bonds which, with the fixed rate structure, had come to sell above par, but felt obligated not to let bond prices fall below par, until after the Accord in March 1951. Some variation in long-term interest rates was allowed; in particular, the Fed allowed prices of long-term bonds to rise above the pegged price, which happened briefly in early 1946.

Price controls were also first imposed in April of 1942, with the General Maximum Price Regulation and were finally lifted with the expiration of the Price Control Act on July 1, 1946. Price controls were not reimposed until the Korean war, when in January 1951 an official freeze on most prices and wages was announced. In the intervening period the only important efforts to control the aggregate price level were voluntary: the Economic Stabilization Agency efforts just before the price freeze with the Korean war, and the voluntary credit restraint program. We thus have a period of 4-1/2 years in which prices were free and long-term interest rates pegged and a one-year period in which prices were free and short-term interest rates were pegged. This time interval, moreover, came immediately after a four year period which, although under price controls, was characterized by a development of "pent-up inflation" in the sense that the money supply increased dramatically under the pegged interest rate.

What does the model predict about the effects of an announcement by the Fed that interest rates are to be pegged at a certain level? Here we are confronted with a basic problem of the transition from one rational expectations equilibrium to another for which rational expectations models are no guide. Sargent and Wallace [1975] highlighted this problem when they pointed out that, in their model, for which $\mu = 1$, the interest rate is related only to future changes in money, hence the money stock and price level are not determined by the fixing of the interest rate. Although in our model $\mu \neq 1$ so that a lagged money stock enters, it is unclear what relevance the money stock before the interest rate peg was announced has to the ultimate rational expectations equilibrium. The price level after a rational expectations equilibrium is reached is still not determined by the model.

If a rational expectations equilibrium is attained under hypothesis 2 then we do know that expression (13) must hold with r_t at the pegged rate, and this means that expected future changes in the money stock must move in such a way as to cause inflationary expectations to move opposite the real rate. If, let us suppose, the real rate and exogenous factors are nearly constant, then the appropriate monetary policy is essentially to keep all changes in M at the appropriate level, equal to the pegged rate minus the real rate. The Fed, to keep interest rates low, essentially must merely keep money growth rates low. Fed policy must be to set an example with small money growth rates, rather than, as was actually the case, to conduct massive open market purchases when rates started to rise. The Fed does not try to offset movements in interest rates in the usual way; rather, it sets a monetary policy which implies deflation (and hence deflationary expectations) whenever the real rate is shocked up, so that the public prevents the nominal rate from ever moving. Clearly, the Fed was not doing the right thing to cause the economy to converge on a rational expectations equilibrium with stable prices at the pegged rate, as they essentially said (though not in these words) in their arguments with the Treasury. We may say that the economy was not in a rational expectations equilibrium of the kind with stable prices, as described by (12) or (13). But it was not in an <u>un</u>stable rational expectations equilibrium either. When price controls were lifted in July 1946 we saw, not a one-shot big increase in the price level but (after a relatively modest immediate jump in prices) a serially correlated smooth increase in prices.[7/] This means that very negative real interest rates, apparently caused by monetary phenomena, could be forecasted during this transition period. This situation persisted for a while and then the economy settled in, not to a hyperinflation, but an ordinary recession.

III. 2 Founding of the Federal Reserve System

In the original Federal Reserve Act of 1913 the first purpose of the Federal Reserve System defined in the opening paragraph is "to provide an elastic currency", and (section 14) "to accommodate commerce and business". From the discussion of the time there is at least one unambiguous implication of this purpose: namely, to provide a larger supply of currency toward the end of the year when the demand for currency was higher due in part to the crop harvest and to Christmas shopping.[8/] Under the national banking system, this higher demand for currency was not accommodated, and the result was pronounced seasonality of nominal interest rates. This seasonality in nominal interest rates apparently vanished after the establishment of the Federal Reserve System, and was apparently replaced by a seasonality in currency in circulation as documented by Macaulay [1938]. Carter Glass [1925] listed the elimination of the seasonal as one of the major achievements of his Federal Reserve Act.

The pronounced decline in seasonality in nominal interest rates after the founding of the Federal Reserve at the end of 1913 can be seen clearly in Figure 1. An additive seasonal factor (plotted with the same scale as the nominal interest rate above) computed with the Census X-11 program is shown. This seasonal is computed using a 3x3 moving average, on seasonals computed as the difference of the corrected series from a 13 month average. This implies a triangular moving average extending over nearly 6 years. Thus, the fact that the seasonal does not disappear immediately in 1914 is mainly due to an artifact of the Census X-11 program. The seasonal does show a marked decline about as soon as it could.

The question that apparently never occurred to anyone then was whether the Fed had, by adopting the announced policy of eliminating seasonals, eliminated a seasonal pattern in real interest rates. A stable seasonal in ex post rates implies a seasonal in ex ante rates since seasonals are forecastable. All our hypotheses may be taken to imply that the elimination of the seasonal in nominal rates should have changed the seasonal in inflation rates so that the seasonal pattern in real interest rates should remain unchanged.

When we look at the seasonal pattern of the ex post real interest rates (Figure 2), we see an apparent disruption[9/] in the seasonal pattern of real interest rates after the founding of the Federal Reserve, but a reassertion of the seasonal pattern roughly as strongly as before. One is tempted to interpret this disrupted period as a transitional period when the economy converged on a new rational expectations equilibrium in accordance with hypothesis 2. There is potentially an element of truth to this story; however, we note that the seasonal pattern in inflation rates had substantially greater amplitude than that in nominal interest rates, and so it is better to say that the seasonal pattern in inflation rates swamped out rather than offset the declining seasonal in nominal rates. All that we can learn with any confidence from this data is that we can't say with any confidence whether a policy of eliminating seasonals in nominal rates reduced the seasonal in real rates. The seasonal in inflation rates is so much bigger, and rather unstable itself, that we can't find any evidence here contrary to the hypotheses. Carter Glass was too quick to congratulate himself on the real consequences of his Federal Reserve Act. [10/]

III. 3 A Policy Rule Change Marked by the Accord

It is commonly asserted that the Accord of March 1951 marked an abrupt change in Fed policy. This was the date that the Fed was freed from the obligation to peg interest rates and a time of new-found concern with monetary aggregates and counter-cyclical monetary policy. One can see from Figure 3 that the rate of growth of the money supply (M1) before the Accord was less strongly seasonal and more marked by erratic longer-term movements. After the Accord (actually, after the war) the growth of the money stock was much more dominated by a very strong seasonal.

The strong seasonal in the money stock, incidentally, first appears around 1942 when interest rates were pegged and, of course, what seasonality in nominal interest rates still remained was then totally eliminated. It appears that the Fed revised its seasonal adjustment factors at this time and then, following the Accord, became concerned that the seasonally adjusted money stock should grow smoothly. In so doing, the Fed perpetuated the seasonal movements in the money stock that were appropriate to a short-term interest rate with no seasonal for the period 1942-50. Subsequent estimates of seasonal factors would tend to remain unchanged as long as the Fed perpetuates this seasonal. Apparently, the seasonal pattern in money demand became more pronounced after the war, and so a seasonal pattern in nominal rates has reappeared, as documented by Diller [1971] and Sargent [1971].

It appears, then, that there was a substantial change in the Fed policy rule after World War II. If we can assume that the stochastic structure of the rest of the economy did not also show an equally substantial change following the war, then we can look at the behavior of the real interest rate and perhaps find some disconfirmation of our hypotheses if the behavior of real rates changes.

A plot of the ex post real short term interest rate (the 4-6 month commercial paper rate minus the succeeding 5 month change in the wholesale price index) appears in figure 4 and the interest rates and inflation rates in figure 5. Indeed, there is a striking change at the time of the Accord. The last big movement downward in the real interest rate was due to the surge in inflation at the end of 1950 which provoked the Accord, as well as the price controls of the Korean War. After that, there is never again such a big movement in ex post real interest rates.

These ex post movements in the real interest rate before the Accord are not an indication of movements in rationally expected real interest rates unless they are forecastable. The apparent serial correlation in figure 4 suggests that they are, and this is confirmed by the simple autoregressions in Table I. The F tests indicate significant coefficients except for the period immediately after the founding of the Fed. The standard deviation of the fitted value (the lower figure in the right-most column) which is a measure of the standard deviation of the true rationally expected real interest rate is m ch higher before 1951 than after.

To the extent that we are willing to assume that the structure of the rest of the economy was the same before and after the Accord, these results clearly provide further disconfirmation of hypothesis 1. It is true that the period before 1951 was characterized by bigger wars than the period after. The depression also came before (although it is less clear that this represents a change in the structure of the economy). Nonetheless, the change in the stochastic behavior of real rates with the Accord is so striking that one is tempted to conclude that the change in monetary policy had something to do with it.

Whether or not the change also disconfirms hypothesis 2 is not something we can say with any assurance. Indeed, given that the monetary policy is not deterministic, and cannot be described in terms of just a money stock rule or just an interest rate rule, then we have not given the hypothesis a precise enough definition to evaluate it formally.

One might attribute the greater movements in the real rate before the Accord merely to greater unforecastable monetary shocks before the Accord. By the same token the relatively low variance of real rates before the founding of the Fed might be ascribed to a more predictable monetary rule under the National Banking System. This argument would not apply to the pegged rate period, between 1942-51, when monetary policy was quite forecastable.

It is not obvious whether or not Fed policy was more or less predictable in the 20s, say, as compared with the 60s. One must remember that big movements in the money stock are no indication of unpredictability since presumably they were triggered primarily by economic conditions in a way that may well have been understood by businessmen at the time. Monetary policy actions need not be known in advance for there to be predictability in this sense, as long as these are revealed by public information before they take place.

We do know that a change in the policy rule occurred after the Accord. It would not be unreasonable to attribute the change in the behavior of real interest rates to the observed change in the systematic policy rule, and thus consider this change as evidence against hypothesis 2. Unfortunately, we cannot feel very comfortable in our assurance that this is so. We are left, then, with only a suggestion that hypothesis 2 might be misguided. Barring a controlled experiment contrasting alternative deterministic, announced policy rules, we are unlikely ever to find better information concerning the direct empirical implications of hypothesis 2.

Before we conclude, however, we note that a recent literature on nominal interest rates for the period 1953-1971 alone might seem to lead us to a different evaluation of the hypotheses. This literature, which was initiated by Fama [1975], has confined attention to this period because it is claimed to represent the only available time period in which the data on inflation rates are good and in which prices are uncontrolled. He said to study real rates before 1953 is "meaningless" because the Bureau of Labor Statistics used poorer sampling techniques before 1953 in computing the consumer price index, (which Fama used) in that it sampled more items on a three month basis than is the case today. If one looks at figure 4, one notes that this period (marked off between parallel lines) shows remarkable stability of the real rate of interest.[11/] This was also a period when the Fed apparently thought it was conducting countercyclical monetary policy, and is usually described as having caused at least one "credit crunch". Fama's evidence appears then to be evidence which makes us less sure of our dismissal of hypothesis 1, that the Fed cannot influence real rates at all.

In his paper, Fama showed two remarkable results about short-term interest rates and prices for this sample period, both of which are consistent with his joint hypothesis that *ex ante* real rates of interest are constant and expectations are rational. First, while both short-term interest rates and inflation rates show significant autocorrelation, *ex post* real rates do not. This result can be seen again by looking at Fama's monthly data on one-month treasury bill rates and one-month inflation rates (figure 6). The inflation rate appears approximately as white noise superimposed on the interest rate series, except for the period 1960-66 when the short rate shows a trend not matched by a trend in inflation rates. The serial correlation we observed in Table I came about, apparently, from post-1971 data and perhaps also from our use of five-month inflation data, which is smoother than one-month data. Second, Fama showed that if inflation rates are regressed on interest rates the coefficient of the interest rate is nearly one (.97, t = 10.0, with his data) and then when the lagged price level is added as a second explanatory variable the coefficient of the interest rate remains near one (.87, t = 7.2) while the lagged inflation rate has a small coefficient (.11, t = 1.6) which is insignificant.[12/] It seems at first remarkable that the lagged inflation rate should be of so little benefit in forecasting inflation, but when one looks at the data one sees why this is the case. There is a great deal of month-to-month noise in the consumer price index, so that the lagged inflation rate is a poor indicator of current inflation. What is more remarkable is that the coefficient of the interest rate should come out so close to one, which is its theoretical value if the ex ante real interest rate is constant and inflation anticipations are true mathematical expectations.

It should be pointed out that under Fama's hypothesis residuals are serially uncorrelated, and if we wished to estimate the coefficient of the interest rate then ordinary least squares is appropriate and the standard errors not compromised by possible serial correlation. If our theory is that the after-tax real rate is constant, then this coefficient is an estimate of $1 - \tau$, where τ is the marginal tax bracket of the "representative investor". If we assume normal residuals, then ordinary least squares is clearly the appropriate procedure under Fama's hypothesis to estimate the coefficient in the regression. [13/] Fama's regression of inflation on interest rates alone provided an estimate of $1 - \tau$ so close to one as to imply that the "representative tax bracket" is zero. Feldstein and Summers [1978] concluded that the after tax real interest rate relevant to the typical investment decision should be computed with, in effect, $(1 - \tau)$ roughly in the vicinity of .8 to 1.0, depending on depreciation and equity yields. [14/] Fama's estimate of .87 with the inflation variable in the regression is dominated by the previous estimate, since by Fama's theory the inflation rate is an extraneous variable in the regression.

If we are instead interested, however, in an alternative hypothesis which makes inflation rates unrelated to interest rates and serially correlated, then the ordinary t-test on the coefficient is not valid. The t-test is a likelihood ratio test in which the universise does not include the possibility of serially correlated residuals. Thus, we do not know from Fama's highly significant coefficient on the interest rate whether or not the observed relation between interest and inflation might easily have come about by a "trend" or "long cycle" or other low frequency component in the interest rate which by sheer chance happened to be correlated with a similar component in the inflation series. Fama's good Durbin-Watson statistic is no assurance, as Granger and Newbold [1977] have pointed out, that this is not a problem. One can get some impression of the likelihood of such an alternative explanation of the correlation between interest and inflation by looking at Figure 6. Clearly, the short-run movements in the price level are not explained by the interest rates. This impression is confirmed by running Fama's regression with the dependent variable lagged or led, to throw it out of alignment with his interest rate data. The fit of his equation is hardly changed. The R^2 rises from .29 in Fama's regression to .30 with a led inflation rate as the dependent variable and falls to .27 with a lagged inflation rate as the dependent variable.[15/] In any event, the alignment is not really correct with Fama's regression either. Fama's interest rate data are based on midpoints of bid-asked spreads for the last day of the preceding month. The Bureau of Labor Statistics [1971] reports that it collects food prices on three consecutive days early in the month. Thus food prices, which in 1971 had a total weight of .224 in the consumer price index, are nearly 30 days out of alignment.[16/] Rents and items for which prices are obtained by mail on the other hand are reported as of the 15th of the month, and the pricing of other items priced monthly extends over the entire calendar month. Many items are still priced only every three months. We thus could not hope with such data to find a short-run (or high frequency) relationship, and it is hardly appropriate to dismiss results based on earlier data for this reason.

The explanatory power in the interest rate series does not come about from a simple trend either. If one runs Fama's regression with a linear time trend term added, this variable does not come in as significant. The explanatory power instead comes primarily from a couple of humps in the interest and inflation series. The first hump begins at the bottom of the recession which occurred in 1954 and ends at the bottom of the recession which occurred in 1958. The other hump starts after the credit crunch of 1966 and ends in the recession of 1971. Some explanatory power also appears to reside in the downturn of interest rates in the recession of 53-54, at the very beginning of the sample. In contrast, the period between 1958 and 1966 shows an upward trend in interest rates with no matching uptrend in inflation rates. Carlson [1977] showed that Fama's regression fits very poorly over this sample period, and the hypothesis that the coefficient is one can be rejected.

The remarkable thing about Fama's paper cannot be seen in the paper itself but in the fact that his critics did not find any regression results over the entire sample which strongly contradicted his. One would think that someone through data dredging could come up with another variable which dominated the interest rate as a predictor of inflation, but that appears not to be the case. Nelson and Schwert [1977] and Hess and Bicksler [1975] used the highly regarded Box - Jenkins forecasting techniques to produce a forecast of future inflation based on lagged inflation rates. When Nelson and Schwert added this forecast to Fama's regression of inflation on interest rates over the entire sample period (1953 to 1971) the R^2 was increased only to .31 from .29. The coefficient of the interest rate fell from .97 in Fama's regression to .65, and the Box-Jenkins forecast had a coefficient of only .38. The coefficient of the Box-Jenkins forecast was significant (with a t statistic of 2.4, in contrast to the t of 1.6 for the lagged inflation rate alone) and so Nelson and Schwert concluded that they had rejected Fama's hypothesis, but they were also forced to conclude that the interest rate carried additional information not in the Box-Jenkins forecast. Other critics were able to find other forecasting variables which pushed up the R^2 a little more. Carlson [1977] added the employment/population ratio to Fama's regression and this variable was highly significant and boosted the R^2 to .36. Still, the coefficient of the interest rate was .64. Joines [1977] added the three lagged values of the whosesale price index to Fama's regression, which were also highly significant, boosting the R^2 another increment up to .37, but still the coefficient of the interest rate remained at .77.

We thus concur with Fama that his results and the results of his critics do suggest that most of the variation in nominal short rates in his sample period can be attributed to inflationary expectations. Fama's results must give pause to those who believe that inflationary expectations are highly sluggish or follow a trend and that medium-run movements in short-term interest rates are movements in _ex ante_ real rates.

It is possible to get an estimate of the variance of the _ex ante_ real interest rate from Fama's regression of inflation on interest if one is willing to assume that the real rate of interest is uncorrelated with the predicted inflation rate. It is easy to see this as an application of the well-known theorem which states that, in a simple regression, if there is a measurement error in the independent variable, the probability limit of the estimated coefficient is biased downward by a factor which is the ratio of the variance of the true independent variable to the variance of the measured independent variable. Here, we take the variation in the real interest rate as the "measurement error". If we ascribe all of the deviation of the estimated coefficient of the interest rate from one to this source, then this implies that with an estimated coefficient of .98, the variance of the real rate is only about 2% of the variance of the observed interest rate, which implies that the standard deviation of the real rate is about 20 basis points. Nelson and Schwert used this kind of argument to arrive at an estimate of the variance of the real rate of interest, but they based their estimate on a different regression: of the change in the rate of inflation on the difference between the interest rate and the lagged inflation rate which produced a smaller coefficient (equal to .89). Under Fama's hypothesis, the coefficient should again be one. If we take the real rate of interest again as the "measurement error" of a true independent variable which is the inflation forecast minus the lagged actual inflation rate and if we assume that the measurement error is uncorrelated with the true independent variable, then by the same reasoning we come up with an estimate of the variance of the real rate of interest which is 1 - .89 = .11 times the variance of the interest rate minus the lagged inflation rate, which then implies a standard deviation for the real rate of 80 basis points.

These estimates of the variance are suggestive, although they must have substantial sampling error (not discussed by Nelson and Schwert). They do suggest smaller movements in real interest rates than many people expected to see.

III. 4 Time Series Analysis of Real Rate and Money Stock Data

From the sound of the hypotheses, it would appear that a Granger or Sims test of causality (see Sims [1978]) from money to real interest rates and a test of the effects of anticipated versus unanticipated money on real rates along lines suggested by Barro [1978], would be relevant to their evaluation.

Granger and Sims tests of causality from the change in the log of the money stock to _ex post_ real interest rates as shown in Figure 4 appear in Table 2. Seasonality was handled in two ways. In some regressions, a seasonal dummy was added to the regression. For other regressions the data was first Fourier transformed, both real and imaginary parts were then set to zero in a band of width $\pi/12$ around the seasonal frequency and the series were then inverse Fourier tranformed to produce a deseasonalized series. Data for the Sims tests was also quasi-first differenced with filter $(1-.75L)^2$.

The results of these causality tests are that, for the post-war period, money unambiguously causes real rates. Clearly the stochastic structure of the series has changed since the Accord, since no causality is found for the pre-Accord period.

Barro tests reported in Table 3 use data series DM (change in the log money stock), DMR (Barro's estimate of the public's forecast error at time t for the change in the log money stock at time t), and G/y (real government expenditure over real GNP) from Barro [1978], Tables I and II. The dependent variable is the one-year (annual average) Treasury bill rate or the rate on the Treasury bill whose maturity is closest to one year minus the lead one-year inflation rate DP from Barro [1978] Table 2. Neither the DM nor the DMR terms are significant in these regressions, which seems odd, since the Granger and Sims tests found, with different data, that money causes real rates. The F statistic is, however, nearly significant at the 10% level in the last regression. The most intesting observation that arises here is that in the regression in which DM is excluded, all variables have the sign we would expect. All DMR terms have negative coefficients and G/y has a positive coefficient.

What do these results mean? One interpretation along lines suggested by the literature on rational expectations and the natural rate of unemployment hypotheses follows from the assumption of a structural relation implying that real interest rates respond <u>linearly</u> to the change in the log money stock and expectations of future changes in log money stocks:

$$\rho_t = \zeta_t + \sum_{i=0}^{n_1} \phi_i \Delta m_{t-i} + \sum_{i=0}^{n_2} \sum_{j=0}^{n_3} \psi_{ij} E_{t-i} (\Delta m_{t-i+j}) \qquad (14)$$

where ρ_t is the rationally expected real interest rate, m_t is the log money stock, ζ_t is a stochastic process representing the real forces that causes movements in the real rate even when the money stock is predictably growing along a constant growth path, ϕ_i and ψ_{ij} are coefficients, and E_{t-i} denotes expectation conditional on information available at time t-i.

The <u>ex post</u> real rate $r_t - p_{t+1} + p_t$ equals the rationally expected real interest rate plus an error term: $r_t - p_{t+1} + p_t = \rho_t + \eta_{t+1}$, where the error term is uncorrelated with all data known at time t and hence is itself serially uncorrelated but may be correlated with information acquired between t and t+1.

In terms of this formulation, hypothesis 1 may be interpreted to mean that ϕ_i and ψ_{ij} are all zero, so that $\rho_t = \zeta_t$ and $r_t - p_{t+1} + p_t = \zeta_t + \eta_t$. We shall assume for the moment that ζ_t is constant. Then, Fama's tests are appropriate and Barro's tests should find all DM and DMR terms insignificant (as we in fact found) although a DMR_{t+1} term may be significant insofar as it affects η_{t+1}. Granger or Sims tests should show that money does not cause real rates, since, as Fama noted, <u>ex post</u> real rates will be unforecastable white noise.

Hypothesis 2 may be interpreted as a restriction on the coefficients of

(14), namely:

$$\rho_t = \zeta_t + \sum_{i=0}^{n} a_i(\Delta m_{t-i} - E_{t-i}(\Delta m_{t-i})) \qquad (14')$$

so that only surprises in monetary policy $\Delta m_t - E_t \Delta m_t$ affect real rates. The lagged terms are included to allow for persistence in the effects of these surprises. Now, Fama's tests are no longer appropriate even if ζ_t is constant. The Barro type tests should show all DM terms insiginificant, but the DMR terms, which are supposed to represent $\Delta m_t - E_t(\Delta m_t)$, might now be significant. Since ρ_t is a simple moving average process whose innovation $m_t - E_t m_t$ is uncorrelated with past data a Sims or Granger test using the true ρ_t would show that money does not cause ρ_t, that is, $\rho_{t-1}, \rho_{t-2}, \ldots$ contain all information available for forecasting ρ_t and hence further information in terms of lagged m is of no value.

Hypothesis 3 might be interpreted as a less stringent restriction on (14):

$$\begin{aligned}\rho_t = \zeta_t &+ \sum_{i=0}^{n} a_{0,i}(\Delta m_{t-i} - E_{t-i}(\Delta m_{t-i})) \\ &+ \sum_{i=0}^{n} a_{1,i}(\Delta m_{t-i} - E_{t-i-1}(\Delta m_{t-i})) \\ + \ldots &+ \sum_{i=0}^{n} a_{s,i}(\Delta m_{t-i} - E_{t-i-s}(\Delta m_{t-i}))\end{aligned} \qquad (14'')$$

where s is the policy effectiveness interval. The restriction imposed by this hypothesis is that long term forecast errors (i.e., for a forecast horizon greater than s) have in themselves no effect on ρ. This hypothesis now implies nothing for any of the tests we have examined. One might have thought that it would perhaps imply that, with a Granger causality test, money terms lagged more than s periods would have no effect, but this is not the case. The only test that seems immediately suggested by it would an be extension of the Barro test found by estimating a battery of zero-period, one-period, two-period, etc. forecasting equations, and then taking their residuals as estimates of the terms $\Delta m_t - E_t(\Delta m_t)$, $\Delta m_t - E_{t-1}(\Delta m_t)$, etc. One could then estimate (14") using for ρ the ex post real interest rate. Hypothesis 3 would then imply that coefficients of $\Delta m_t - E_{t-j}(\Delta m_t)$, $j > s$ should be zero, which is in principle testable.

While the above analysis seems to suggest that Granger, Sims or Barro tests, or extensions therof, might well be used to examine the hypotheses, it is useful to bear in mind the stringent assumptions that must be made. These assumptions have for the most part already been pointed out in different contexts by, for example, Sargent [1976] and Sims [1977], so we will cite them only briefly here.

We have assumed first that ζ_t is constant. In fact, it is plausible that real factors have had an impact on real interest rates and that the forecast of ζ_t may be related to lagged money. For example, wartime increases in government expenditure may themselves influence ζ_t and are also correlated with the wartime increases in money. This may mean that Barro, Granger or Sims tests would find that money has an effect on real rates even if hypothesis 1 or 2 true. Barro's contemporaneous G/y term may well fail to correct for such effects. On the other hand, even if all the hypotheses are false it is possible, as Sims [1977] has pointed out in a more general context, that if the Fed has been trying to stabilize real interest rates, i.e., offset ζ_t, causality tests might lead one to conclude that money has no effect on real interest rates. These problems seriously limit the usefulness of the above tests for the purpose of examining our hypotheses.

Another problem with the Granger or Sims tests in this context is that our hypotheses relate to unobservable rationally expected real rates and we use in the tests the _ex post_ real rates. With either Granger or Sims tests the real rate must appear on the right-hand side of the equation, so we have an errors in variables problem (which is not completely solved by using some other estimate of the rationally expected real rates). Then, even if hypothesis 2 is true, m may appear to cause real rates, since lagged Δm may provide information about $\Delta m_{t-i} - E_{t-i}\Delta m_{t-i}$ not obtainable from the lagged real rate

This problem would not arise if we were willing to assume in hypothesis 2 that there is no persistence in the effects of monetary surprises on real interest rates, i.e., $a_i = 0$, $i \geq 1$. Then (so long as problems of time variation in ζ_t do not arise) we could test the hypothesis by checking whether _ex post_ real rates can be forecasted. In effect, we could eliminate the lagged real rate terms from the Granger test by theoretical considerations. Similarly, if the summations in (14") are known to contain only the first term (i.e., $a_{ji} = 0$, $i \geq 1$, all j) then hypothesis 3 could be tested merely by regressing _ex post_ real rates on information known s periods earlier, which should not contribute to a forecast of real rates. However, those who have suggested our hypotheses have made it clear that they are not willing to rule out persistence, so these tests cannot be used.

Another problem with the Barro tests is that it is perhaps not possible to identify the contemporaneous forecase errors, since these rely necessarily on an arbitrary characterization of the forecasting relation and information set of the public. His forecasting equation depends on one contemporaneous variable (a government expenditure term) which appears no more likely to be known at any point of time than is the money stock itself. This term is essential to the model, since without it his forecasting relation would be autoregressive, in which case the DM terms would be linear combinations of lagged DMR terms and hence not distinguishable in the regression.

Finally, whatever we learn about (14) under one policy rule, we do not necessarily know that (14) is a structural relation which is invariant under alternative policy rules, as Sargent [1976] has emphasized.

IV. Conclusion

We will conclude here by listing the salient facts that seem relevant to each of the three hypotheses. Since the hypotheses are nested, evidence against any hypothesis also serves as evidence against the hypotheses preceding it.

Hypothesis 1 The Federal Open Market Committee knows it can influence nominal rates because it has conducted what Friedman and Schwartz [1963] called "quasi-controlled experiments", i.e., it has moved the money stock in ways and at times that could not be ascribed to reverse causality from economic variables to the money stock. It seems highly improbable that the outcome could be explained in terms of the reaction of inflationary expectations to the shock. We thus feel we can safely say that hypothesis one is wrong.

Fama's evidence serves principally to cast substantial doubt on the conventional argument that medium-run movements in nominal rates must be due primarily to movements in *ex ante* real rates since inflationary expectations are very sluggish. The correspondence of movements in post-Accord nominal rates and the optimally forecasted inflation rates is fairly impressive. One must bear in mind that really short-run movements in nominal rates did not occur enough in the sample period for us to say anything about these movements in nominal interest rates. Fama probably exaggerates the problems with earlier data and our results with these incline us to the conclusion that the relative constancy of real rates in his sample is due to Fed behavior, not the inability of the Fed to shock them. An interesting unanswered question is: why did the Fed behave so as to keep the pre-tax real rate constant? Was this behavior due to their concern with some other variable which responds reliably to this rate?

Hypothesis 2 Direct evidence against this weaker hypothesis can be found only if we can find policy rule changes which affect the predictable component of monetary policy. Barro claims to have decomposed changes in the money stock into predicted versus unpredicted components for the post-war period, but his claim is not terribly convincing and in any event he assumed a constant policy rule. Granger or Sims causality tests are suitable as tests of this hypothesis only under some artificial assumptions.

One policy change that appears to relate to the way the Fed reacts to public information is marked by the Accord in 1951. This change was a once-and-for-all change ascribable largely to factors whose origin lay in politics and theoretical economics, and in this sense it too was exogenous. There is a dramatic change in the behavior of real interest rates that seems, looking at the data, to coincide with the Accord. Unfortunately, we do not know for sure that this change is due to a change in the systematic policy rule or just a change in the magnitude of the random components. It is also possible, moreover, that other changing variables were responsible for the change in the real rate's behavior. We also saw, for example, a dramatic rise in income tax rates dating from World War II, and although this change does not coincide with the change in real rate behavior, one could not rule out that the two are related. Paradoxically, pre-tax real interest rates were more stable after the tax rates were increased, when the theoretical case for constant pre-tax real rates was apparently weakened.

Hypothesis 3 Direct evidence against this yet weaker hypothesis can be found only if we can find changes in the monetary policy rule which relate to information which was known in advance for a length of time exceeding the policy effectiveness interval. We considered one such shock to policy which relates to information forecastable into the indefinite future: i.e., the seasonal. The Fed announced a policy at the time it was founded of reducing the seasonal in nominal rates. The Fed succeeded in reducing this seasonal, but there is no evidence that it affected the seasonal in real rates.

The most important potential source of evidence against this hypothesis, as well as hypothesis 2, comes not from the macroeconomic data but from other considerations. If we combine hypothesis 3 with a demand for money equation and a stability condition, then we are led to the conclusion that the price level bears a certain realtionship to information about monetary policy known in advance by more than the policy effectiveness interval. While it is plausible that in some comparative steady states characterized by, say, different money growth rates, this might work out to be true, it does not seem likely that new information about discrete future Fed policy actions would become optimally incorporated in the price level over any policy effectiveness interval. Most prices do not seem to be set that way.

We conclude that none of the hypotheses is likely to be so strictly correct as to rule out completely a predictable effect of systematic monetary policy on expected real interest rates. This does not by itself establish that there is a role for monetary policy in improving economic welfare. This conclusion, moreover, rests on our impression as to how prices are set and not on any formal statistical evidence, which cannot be effectively brought to bear either for or against our conclusion. We hope, however, to have clarified why the complete non-controllability of expected real interest rates should not be, as many seem to have concluded recently, a cornerstone for macroeconomic modelling.

FOOTNOTES

1/ This literature is surveyed by Poole [1976] and Shiller [1978].

2/ Data before 1951 is not usable, Fama [1975] said, because "in effect a rich and obstinate investor (i.e., the Fed) saw to it that treasury bill rates did not adjust to predictable changes in inflation rates".

3/ In the Phelps-Taylor model [1977] prices are assumed fixed by firms one period in advance, and the money supply fixed by the Fed based on information not known one period in advance. If Fed policy were known one period in advance, then taking expectations of their expression (8) based on information known at time t-1 and using their expression (6), one finds that the money stock drops out of the real part of their model altogether.

4/ The economy may never reach a new rational expectations equilibrium, or may never be in one. Those are important theoretical possibilities that lessen the appeal of models which assume expectations equilibria (see Shiller [1978]).

5/ Slight variations in the definition arise due to different ways of handling compounding. For example, we might define the real interest rate as one plus the nominal rate divided by one plus the rate of inflation. We disregard the differences among these definitions in what follows.

6/ If monetary shocks show persistence, i.e., serially uncorrelated movements in ϕ create serially correlated movements in the real rate, as represented, for example, in expression 14' below, then the real rate will not return to "target" immediately.

7/ See Figure 5 below.

8/ In its first annual report to Congress [1915], the Federal Reserve Board seems to say, in clear language, that it will mitigate seasonal fluctuations in interest rates:

> "It should not, however, be assumed that because a bank is a Reserve Bank its resources should be kept idle for use only in times of difficulty, or, if used at all in ordinary times, used reluctantly and sparingly.... Time and experience will show what the seasonal variation in the credit demands and facilities in each of the Reserve Banks of the several districts will be and when and to what extent a Reserve Bank may, without violating its special function as a guardian of banking reserves, engage in banking and credit operations.... There will be times when the great weight of their influence and resources should be exerted to secure a freer extension of credit and an easing of rates in order that the borrowing community shall be able to obtain accommodations at the lowest rates warranted by existing conditions and be adequately protected against exorbitant rates of interest. There will just as certainly, however, be times when prudence and a proper regard for the common good will require that an opposite course be pursued and accommodations curtailed." [The Board said it gave]" certain assurance that whatever funds might be necessary for the gradual and orderly marketing of the cotton crop would be available at moderate rates."

9/ The disruption is not due to the spectacular deflation of 1920, since the Census X-11 program automatically excludes such outliers. The Census X-11 is still capable of producing spurious seasonals. Sargent [1971] demonstrated the existence of a pre-1913 seasonal (as well as a post World War II seasonal) in short-term interest rates with spectral analysis.

10/ The seasonal pattern in real interest rates may be spurious. Since nominal rates showed less pronounced seasonality than inflation rates, there was an incentive in the fall, when agricultural prices were low, for farmers to hold their crops off the market and borrow at the nominal rate. Their efforts to do so was apparently hampered by credit rationing by the banks. It is possible that there was no seasonal in real rates actually available to farmers.

One effect of Fed policy not shown in the data may be the reduction of credit rationing in the fall. Hypothesis 2 would then suggest that the seasonal pattern in inflation should disappear, making for a spurious apparent reduction in real rate seasonality, which we do not observe. Instead, this interpretation suggests the Fed may have introduced a seasonal in real rates that did not exist before.

11/ This figure shows the inflation as measured by the wholesale, rather than consumer price index. However, the plots using the consumer price index, for the period for which it is available, look similar.

That Fama's hypothesis did not hold before is certainly well known. The famous "Gibson Paradox", noted as early as 1844, was a positive correlation between interest rates and price levels, not rates of change of prices. While the correlation is most pronounced for long-term interest rates, it was also present with short-term rates for British data in the century before World War II, and over this period there was really no correlation between short rates and inflation rates (Shiller and Siegel |1977|).

A plot of an ex post real British consol rate (subject to an arbitrary assumption about inflation rates past 1977 which makes the more recent real rates unreliable) from 1729 to the present appears in Shiller and Siegel |1977|. This real long-term interest rate is very volatile and at times negative. It was found that nominal long-term rates over this period moved in such a way as to exacerbate, rather than mitigate, the effects of inflation on long-term real rates, i.e., nominal long rates were negatively correlated with the appropriately defined long-term inflation rate.

12/ Fama used the rate of change of the purchasing power of money as his dependent variable, i.e., his dependent variable is $\Delta_t = -(P_t - P_{t-1})/P_t$ rather than $(P_t - P_{t-1})/P_{t-1}$. When we used his data, we multiplied Δ_t by -1200 and called this the inflation rate. We have reversed the sign of his coefficient to accord with our definition.

13/ The residuals do, however, fail the David-Hartley-Pearson studentized range test of normality at the 5% level. The studentized range in the residuals regression of inflation on a constant and the interest rate for the full sample period is 6.42, and the Durbin-Watson statistic is 1.77.

14/ Feldstein and Summers' arguments applied to long-term interest rates, which might be connected, via term structure phenomena, to short rates.

15/ These statistics refer to a regression of the inflation rate on a constant and the interest rate over the longest possible sample with the data series shown in figure 6.

16/ Fama's inflation rate is computed as $\Delta_t = (P_{t-1} - P_t)/P_t$, so the food price component of the change applies to the period from the beginning of the preceding month to the beginning of the current month. The interest rate series gives the treasury bill rate at the end of the preceding month, which matures over the current month.

The monthly change in the food price index is more volatile than other components and had a correlation of .71 with the monthly change in the consumer price index over Fama's sample period. Thus, the led inflation rate may be the more appropriate dependent variable.

TABLE I

EX POST REAL RATE AUTOREGRESSIONS

Time Period	COEFFICIENT OF				$\bar{R}^2$	F	σ(RESID)
	CONST	SEASONAL	DEP_{-1}	DEP_{-2}	t_{next}	Sig(F)	σ(FITTED)
1901-II to 1913-I	1.73 (1.08)	4.79 (2.35)	.383 (2.02)	-.482 (-2.59)	.244 (-1.48)	3.47 3.54	4.56 2.59
1915-II to 1929-II	.620 (.107)	1.48 (.184)	.493 (2.49)	-.186 (-.942)	.104 (-.416)	2.08 12.87	21.6 7.36
1901-II to 1929-II	.236 (.081)	3.62 (.884)	.481 (3.55)	-.185 (-.137)	.151 (-.679)	4.31 .859	15.33 6.45
1915-II to 1950-II	-2.66 (-.926)	4.33 (1.07)	.493 (4.04)	-.116 (-.950)	.172 (-.327)	5.85 .131	16.9 7.71
1952-II to 1977-II	.100 (.135)	.375 (.369)	.324 (2.38)	.394 (2.91)	.360 (-1.01)	10.4 (.002)	3.59 2.69

Dependent variable is the ex post real rate (i.e., the 4-6 month prime commerical paper rate minus the succeeding actual 5 month inflation rate computed from the wholesale price index) as shown in figure 4. Data is semi-annual, for June and December. Seasonal dummy is zero in June, 1 in December. Numbers in parentheses are t-statistics, t_{next} is t-statistic of dependent variable lagged one more time in a different regression (presented here instead of a Durbin-Watson statistic). σ(RESID) is standard error of of regression, σ(FITTED) is estimated standard deviation of fitted values, equal to $\sigma(RESID)\sqrt{\bar{R}^2/(1-\bar{R}^2)}$

TABLE II

GRANGER - SIMS CAUSALITY TESTS

SAMPLE	TYPE	SEASONAL DUMMY	F STATISTIC	DEGREES OF FREEDOM
1928-II to 1977-II	Granger	No	3.09*	5, 87
1928-II to 1977-II	Granger	Yes	1.40	5, 86
1929-II to 1975-II	Sims	No	1.71	4, 80
1928-II to 1950-II	Granger	No	1.55	5, 33
1928-II to 1950-II	Granger	Yes	1.14	5, 32
1929-II to 1948-II	Sims	No	0.58	4, 26
1955-II to 1977-II	Granger	No	5.22**	5, 33
1955-II to 1977-II	Granger	Yes	3.05*	5, 32
1957-II to 1977-II	Sims	No	18.9**	4, 28

NOTES: Tests indicate whether the change in the log of the money supply (from time series illustrated in figure 3) causes real rates (from series shown in figure 4). Data is seasonally adjusted unless seasonal dummy appears. For Sims tests, data is quasi first differenced with filter $(1-.75L)^2$. *Ex post* real rate based on nominal rate in a given quarter is considered contemporaneous with the change in the log of the money stock from the preceding quarter to the given quarter. Granger tests involve regressing real rate on five lagged values of the real rate and money variable, a constant, a linear time trend and, if noted, a seasonal dummy. F statistic is test of hypothesis that all lagged money coefficients are zero. Sims tests involve regressing the money variable on 4 lead, a contemporaneous and 6 lagged real rate variables, as well as a constant and linear time trend. F statistic is test of the hypothesis that all lead real rate coefficients are zero. * significant at 5% level ** significant at 1% level.

TABLE III

BARRO TYPE REGRESSIONS

COEFFICIENT OF:

CONST	DMR	DMR_{-1}	DMR_{-2}	DMR_{-3}	DM	DM_{-1}	DM_{-2}	DM_{-3}	TIME	G/y	R^2	D.W.	S.E.	F	F_b
.372	-23.8	-7.15	-17.0	-29.3	---	---	---	---	.023	----	.218	1.46	1.28	1.06	----
(.627)	(-1.22)	(-.371)	(-.900)	(-1,55)	---	---	---	---	(.582)	----					
-7.64	-27.0	-9.45	-31.7	-38.2	---	---	---	---	.191	46.9	.366	1.82	1.18	1.73	----
(-1.93)	(-1.48)	(-.52)	(-1.68)	(-2.13*)	---	---	---	---	(2.12*)	(2.04)					
2.93	11.4	87.7	-30.2	68.5	-39.8	-75.4	36.9	-96.0	.251	----	.550	1.82	1.10	2.03	2.75
(2.53*)	(.192)	(1.40)	(-0.50)	(1.87)	(-.74)	(-1.20)	(.572)	(-2.30*)	(2.87*)	----					
-2.95	17.6	85.0	-42.2	55.2	-52.4	-74.9	46.2	-79.1	.353	34.4	.594	2.04	1.08	2.04	1.96
(-0.60)	(.300)	(1.38)	(-.694)	(1.46)	(-.971)	(-1.22)	(.723)	(-1.83)	(2.96*)	(1.23)					

NOTES: Dependent variable is the annual average monthly per year treasury bill rate series (or 9-12 month rate series when 12 month rate is unavailable) from Banking and Monetary Statistics 1941-70, Board of Governors of the Federal Reserve System, 1976, and Federal Reserve Bulletin) minus 100 times Barro's [1978] inflation variable (DP) for the following year. All other data are from Barro [1978]. DM is the change in the log of the money stock, DMR is the residual in Barro's DM forecasting equation, G/y is real government expenditure over real GNP. Time is 1 in 1952 and 25 in 1976. Sample period is 1952-76. F_b is F statistic to test hypothesis that coefficients of all DM terms are zero. t statistics are in parentheses. * significant at 5% level, ** significant at 1% level.

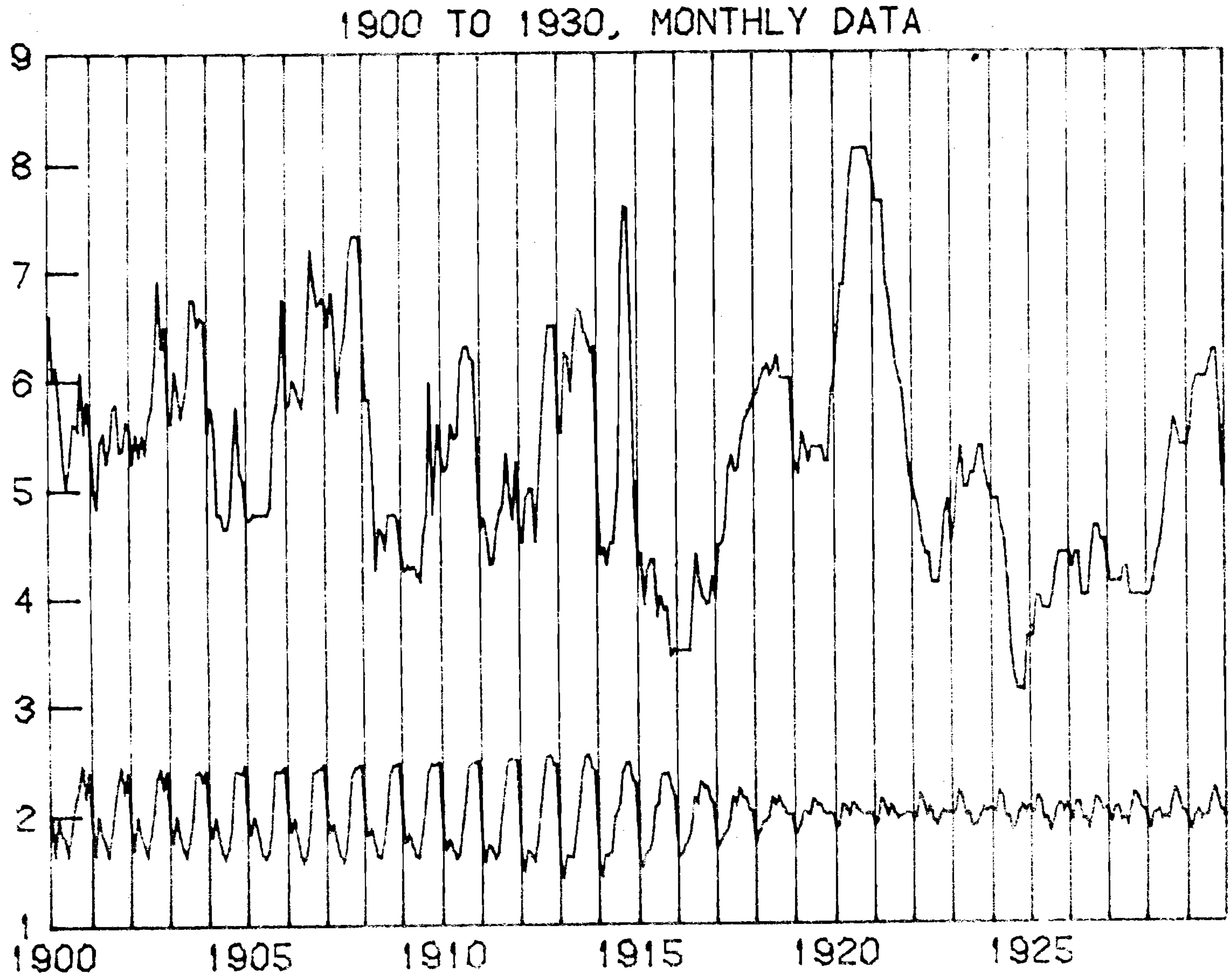

Figure 1 4-6 month prime commercial paper rate (above) and additive Census X-11 seasonal factors (below), monthly data. vertical lines correspond to January of the year noted directly below it. Source of prime rate series: 1900-24, Banking and Monetary Statistics, 1914-41, Board of Governors of the Federal Reserve System 1943, Table 120; 1925-1929, Macro Data Library, Board of Governors of the Federal Reserve System.

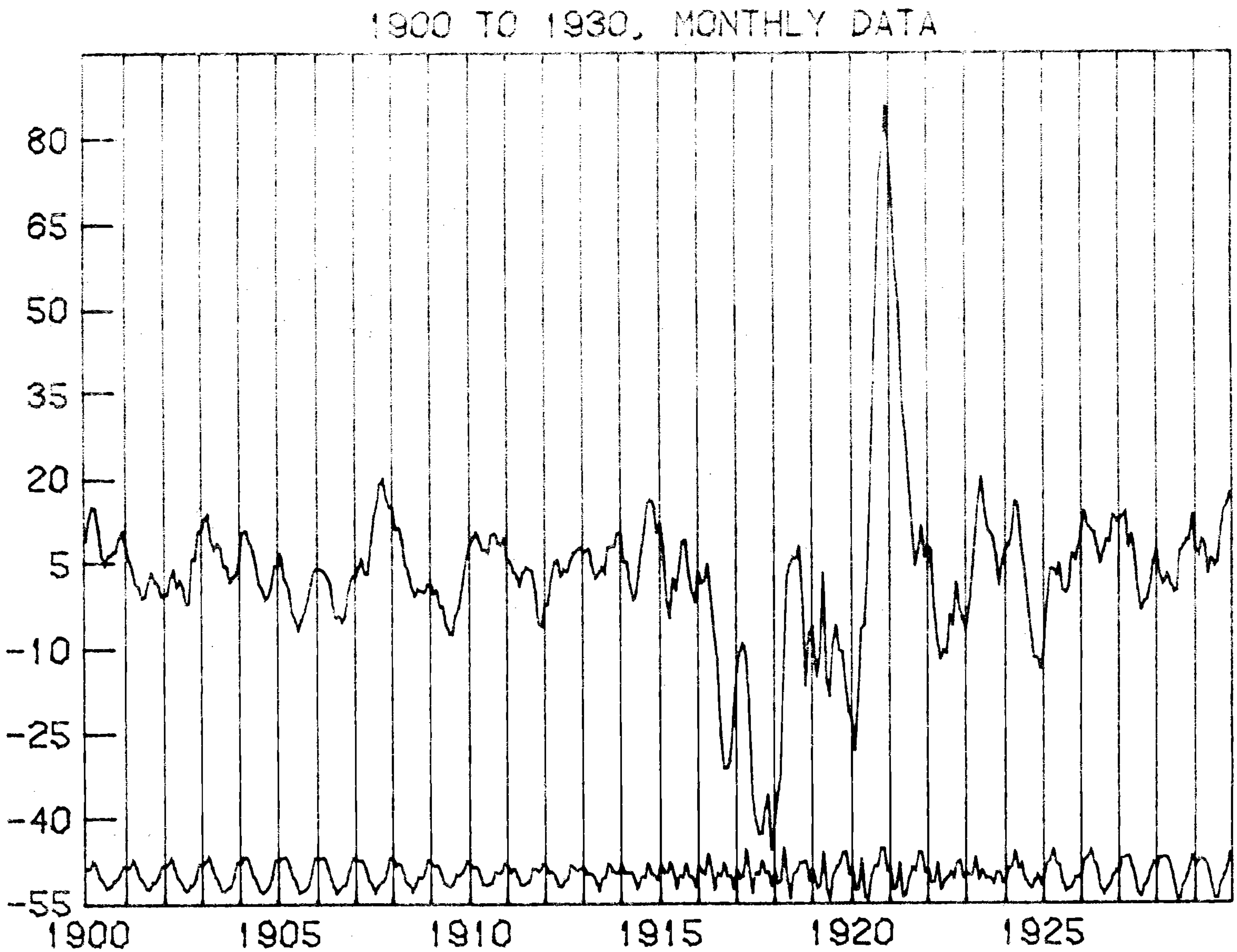

Figure 2 *Ex post* real interest rate, the 4-6 month prime commercial paper rate minus the 5 month inflation rate based on the BLS whosesale price index of all commodities (above) and additive Census X-11 seasonal factors (below). vertical lines correspond to January of the year noted directly below it. Source of price series: Bureau of Labor Statistics, 1900-1913 Bulletin #149 (1914), 1913-19, Bulletin #269, 1920-29, Macro Data Library, Board of Governors.

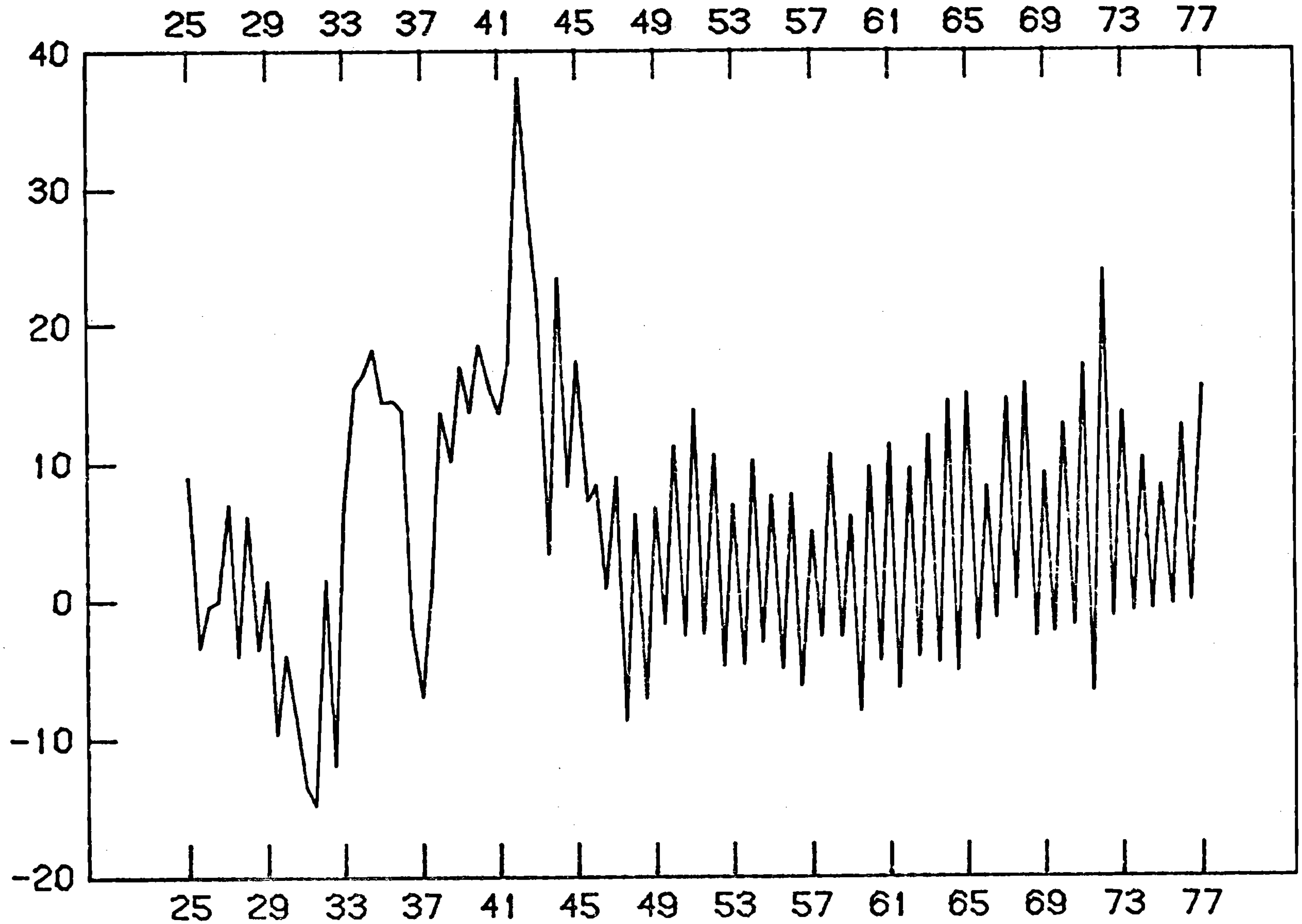

Figure 3 Money growth rates before seasonal adjustment, 6 month percentage change in M1 over succeeding 6 month period at annual rates, 1925-1977, semi-annually (June and December). Marks on horizontal axis correspond to June figure. Source: 1925-40, Banking and Monetary Statistics 1914-41, Board of Governors of the Federal Reserve System, 1943, Table 9; 1941-70, Banking and Monetary Statistics 1941-70, Board of Governors of the Federal Reserve System, 1976, page 5 and Table 1.1, 1971-7 Federal Reserve Bulletin, passim.

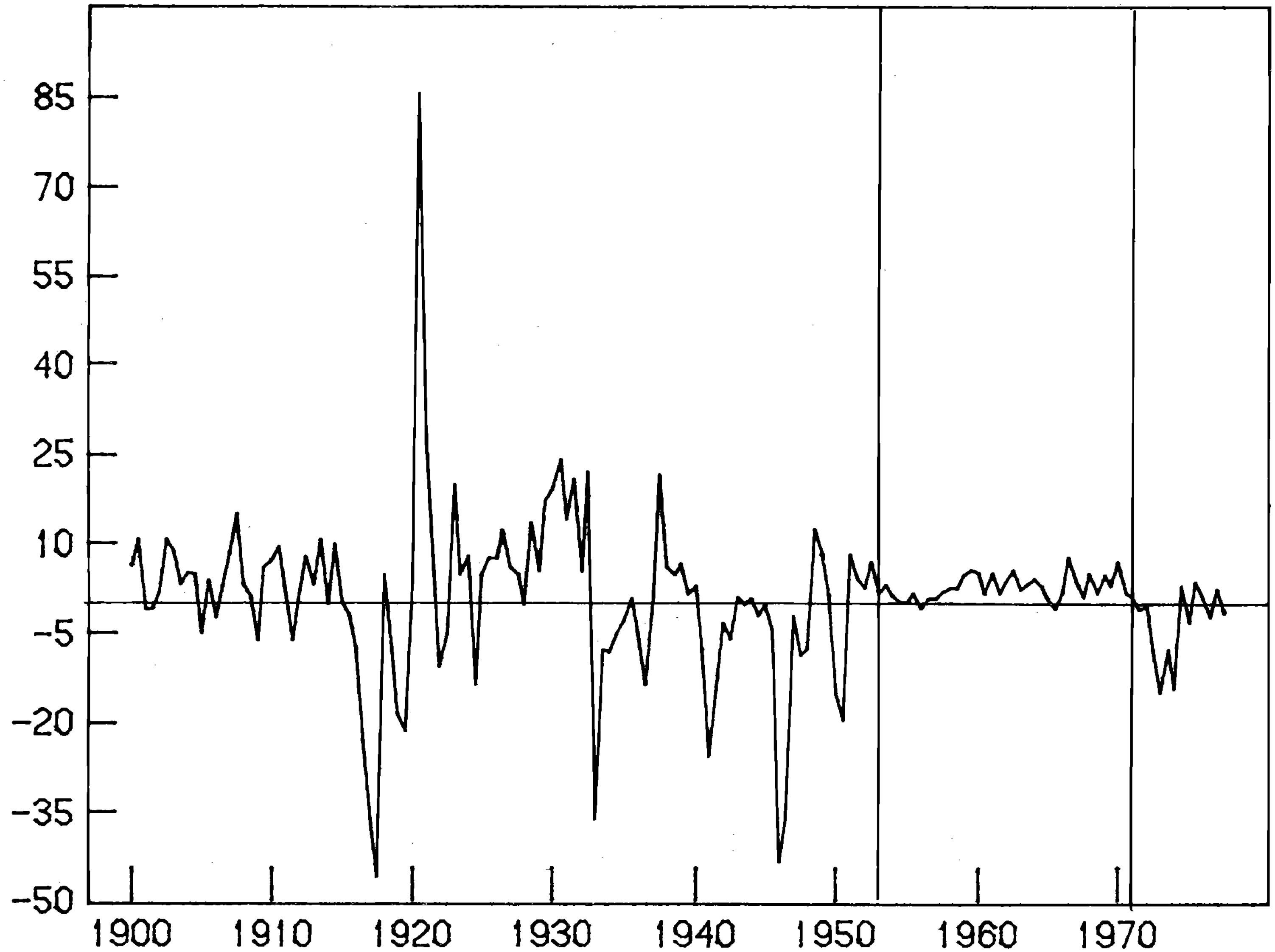

Figure 4 Ex post real rate of interest, 1900-I to 1977-II, June and December, equal to the interest rate minus the inflation rate plotted in figure 5. Marks on the horizontal axis correspond to the June figure. Fama's sample period is enclosed between vertical lines.

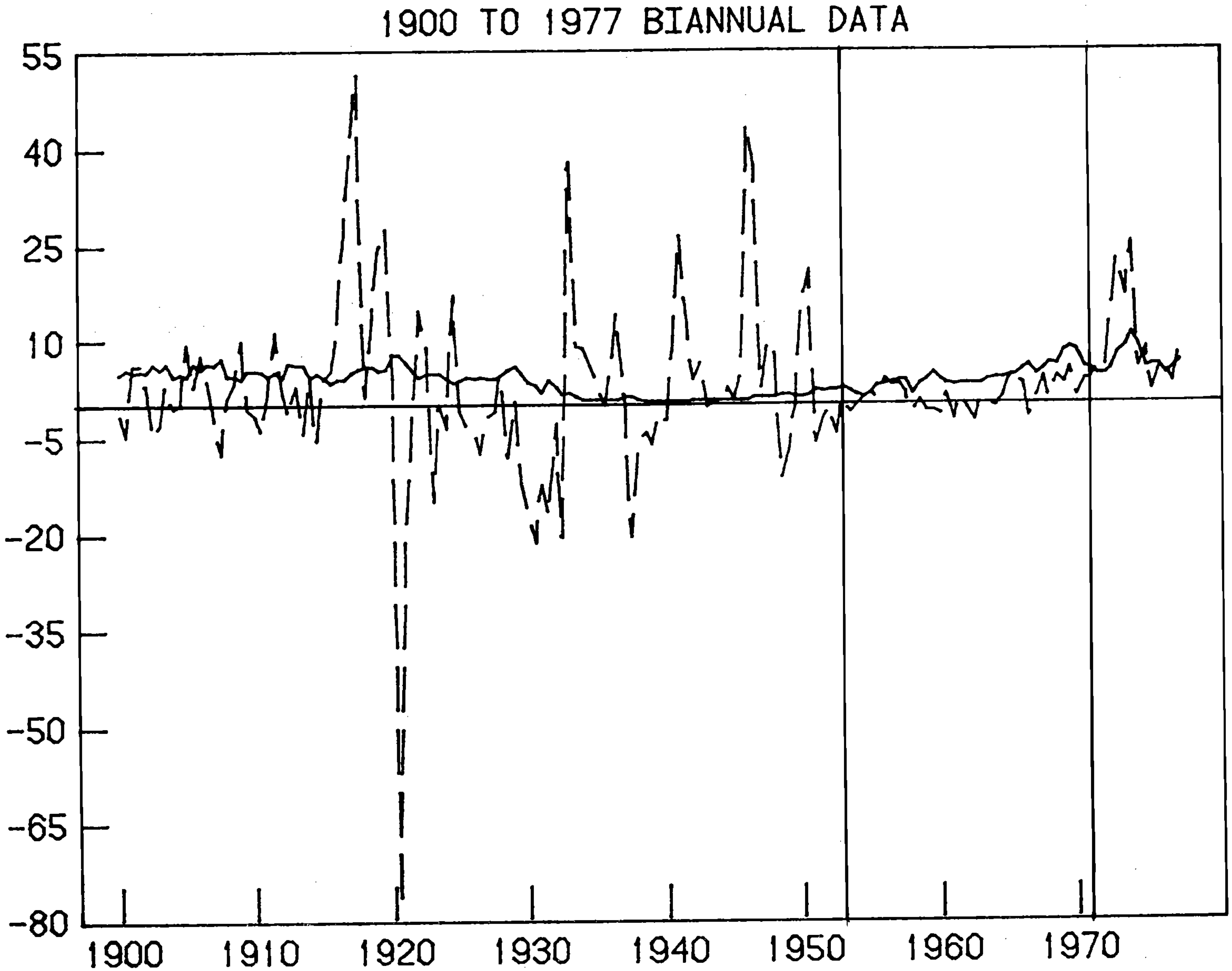

Figure 5 Annualized percent change in the whosesale price index over succeeding 5 months (dptted line) and four to six month prime commercial paper rate (solid line), 1900-I to 1977-II, June and December. Marks on horizontal axis correspond to the June figure. Fama's sample period is enclosed by vertical lines. Source: wholesale price index: Bureau of Labor Statistics, publication noted in Figure 2, prime commercial paper rate: Federal Reserve, publication noted in figure 1.

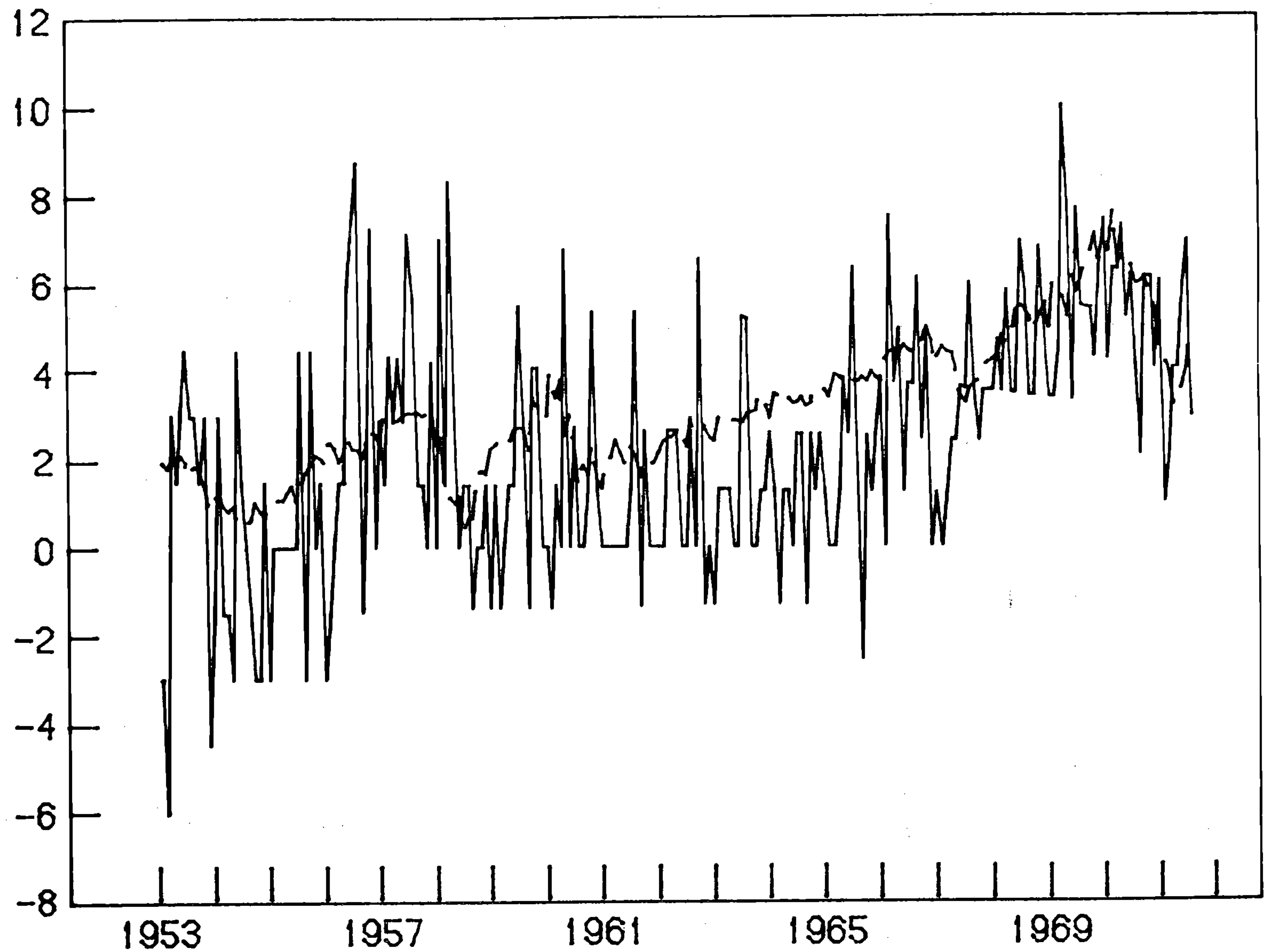

Figure 6 Fama's data, February 1953 to July 1971. Solid line is inflation rate, equal to $-1200\ \Delta_t$ and dotted line is one month treasury bill rate, equal to $1200\ R_t$ where Δ_t and R_t are defined in Fama (1975). Division marks on the horizontal axis correspond to the first month of the year numbered directly below it. Source: Data courtesy of E. Fama.

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