

Pushing on a String? -
An Alternative Approach to the 1930's

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June, 1978

Working Paper #: 117

PACS File #: 3040

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INTRODUCTION

The subject of this paper is one aspect of the money supply mechanism: the management by commercial banks of their asset portfolios and the implications of the asset management decisions for the monetary, or central bank authorities. Given the fractional reserve commercial banking system in this country, the precision with which the monetary authority can achieve its goals, even abstracting from the uncertainties inherent in the system, is limited significantly by the stability of the relationship between reserves and deposits. Even if the monetary authority has perfect control (which it does not, of course) over the level of reserves, considerable discretion still exists for commercial banks in the utilization of these reserves for deposit creation. The study reported here concentrates on this relationship and its implications for monetary policy during the 1920's and the turbulent decade of the 1930's. This period was chosen for it is, in the view of many economists, a period whose events not only were unique in the history of our commercial banking system but also have never been satisfactorily explained. Furthermore, the questions which are addressed in this study provide a convenient vehicle for the demonstration of econometric techniques which logically ought to be included as part of the construction of any macroeconomic model, whether in a partial or general equilibrium framework.

The paper is organized according to the following scheme. Section one provides a background to the events of the 1930's. Some comments on the wisdom prevailing in the 1920's concerning bank asset management are made, followed by a brief survey of the events of the 1930's. A dominant theme in this decade was that the banking system found itself caught in a liquidity trap: it is this hypothesis to which the remainder of the paper is directed. The second part formalizes a definition of the liquidity trap which is both consistent with the views expressed by the monetary

authorities during the 1930's and is amenable to direct empirical testing in a multivariate framework. The third section then presents the formal econometric theory underlying the tests performed in this study and relates this theory in an operational context to the particular definition of the liquidity trap proposed here. The last two sections present the empirical results and some concluding observations.

I. The Banking Experience in the 1930's

Before explicitly considering the events of the 1930's, it is worth noting the background events of the 1920's and the apparent inferences drawn from those events by both banks and the monetary authority. Overall, the twenties comprised a period of relatively stable economic growth and high prosperity. The two recessions of 1923-1924 and of 1926-1927 were so mild as to be virtually unnoticed by all but professional economists. The close timing and high correlations observed between policy actions taken by the monetary authority and movements in aggregate measures of economic activity fostered a high degree of satisfaction with and confidence in the operations of the Federal Reserve System. Indeed, the system seemed to be working so well that the stable relations among aggregates which were observed often came to be regarded as norms for the economy in general and the banking system in particular.

As part of the development of the Federal Reserve System and the framework within which monetary policy was to be conducted came a clear picture of the deposit expansion mechanism for the commercial banking system.^{1/} Once formalized, the simplest framework for the banking system reduced the overall impact of a change in reserves to a multiplier given by the reciprocal of the ratio of reserves to deposits. Furthermore, the data showed very little variation in this ratio between 1921 and 1929; reserves were a maximum of about 9% of deposits in early 1922 and a minimum of about 7.5% of deposits in early 1929. This overall drop in

the ratio over the decade proceeded along the relatively stable trend line which characterized the ratio prior to 1920.^{2/} The inference apparently drawn by both economists and the banking profession was that this stability reflected a constant ratio of reserves to deposits desired by commercial banks.^{3/} Even Keynes, in the Treatise on Money, endorsed this point of view:

"... at any time banks stick closely to their established ratio, and . . . such fluctuations as there are exhibit no correlation with the state of trade."^{4/}

Furthermore, Keynes expressed a view which also seemed to be held by the staff of the Board of Governors of the Federal Reserve System:

"to let it rise above would be to forego . . . a source of profit, since surplus reserves can always be employed in the purchase of bills or investments.

"... all banks use their reserves up to the hilt; . . . they seldom or never maintain idle reserves in excess of what is their conventional or legal proportion . . ."^{5/}

A similar view of the banking system was expressed by E.A. Goldenweiser of the research staff of the Board of Governors in 1925.^{6/}

Not only did the stability which accompanied the creation and operation of the Federal Reserve System imply a stable ratio of reserves to deposits but also the facilities of the Federal Reserve for discounting eligible paper apparently reduced the need of banks to hold excess reserves to meet reserve drains and resultant deficiencies. Thus, monetary policy seems to have been conducted in a way which emphasized the determinants of member banks borrowing from the Federal Reserve. Over the twenties, not only did the reserve-deposit ratio exhibit only minor fluctuations about its trend but also did the proportion of excess reserves in commercial bank asset portfolios remain essentially negligible. These constant

ratios had become accepted as virtually unchangeable and, in fact, the only management policies consistent with good banking practices under the Federal Reserve System by the beginning of 1929; the only deterrent to precise control by the monetary authority over total bank deposits outstanding was considered to be the instability in the level of borrowings by banks from the Federal Reserve.^{7/}

In 1929 the most severe business contraction in modern U.S. history began and this decline was accompanied, over the succeeding years, by changes even more drastic in the monetary sector. Between August 1929 and March 1933 (from cyclical peak to trough) the money stock declined by more than one-third. During this same period suspended operations, consolidations, and mergers reduced the number of operating commercial banks to less than two-thirds of its pre-contraction size. Unprecedented in U.S. banking history was the week-long banking holiday in March of 1933 during which all commercial and Federal Reserve Banks closed their doors. Following the crash of the bull market in October 1929, prices and the general level of economic activity began to decline. The money stock declined about 2.5 per cent in the year following the crash, but few other changes in the banking environment occurred over the same period. The liquidity position of commercial banks changed little over this period, and excess reserves remained negligible as a proportion of assets in bank portfolios.

Beginning in October 1930, the level of deposits in suspended banks began to rise dramatically. By December, banks with total deposits in excess of \$750 million had failed. Fearful of further bank failures, the public began converting deposits to currency at an increasing rate and banks liquidated loans in an attempt to improve their liquidity positions. By early 1931, this first banking crisis had subsided and banks reduced the rate at which they were liquidating loans to meet anticipated crash drains. However, further into 1931 the level of deposits of suspended banks again began to rise. Again banks began strengthening their

liquidity positions and excess reserves were \$130 million by July, 1931--only the second time the level had reached \$100 million or more. Short-term interest rates fell through the latter part of 1931 and 1932 to very low levels as credit demand fell off and commercial banks attempted to strengthen their liquidity positions. There seems to be little disagreement as to the reasons for the rise in the reserve-deposit ratio and, in particular, the growth in excess reserves during this period--banks were attempting to shore up their stock of liquid assets in the face of expected, but uncertain, future cash demands by depositors.

The period from the end of the banking holiday in March 1933 through the end of 1942 has, unlike the previous several years, been one subjected to countless analyses and discussed in terms of numerous theories. The variety of approaches to the period has undoubtedly resulted from the unique events which characterized the monetary sector during that time. The major changes seen reflected a drastic move in the policies of commercial bank asset management. Over the period an increasingly larger proportion of bank assets were held in the form of cash assets (including vault cash, items in the process of collection, and balances held in other commercial banks and in Federal Reserve banks)--this change arose in connection with the emergence of excess reserves in 1932. The second new feature characterizing bank portfolios was the decrease in the ratio of loans to investments; this ratio fell from 2.6 over 1929 to 1.2 by 1933 and ultimately to 0.7 in 1936 and again from 1939-1941. Between 1934 and 1941 it never reached 1.0.^{8/} As commercial banks expanded their holdings of investments over this period, virtually all interest rates declined steadily. For instance, the yield in Treasury bills fell, based on annual averages, from 0.515 per cent in 1933 to 0.143 per cent in 1946. Following an increase to 0.447 per cent in 1937, the yield declined steadily to 0.014 per cent in 1940.^{9/}

Over this same period the level of excess reserves grew to an all-time high, both in absolute and in relative terms. From the \$130 million level in 1931, excess reserves reached a high of \$6.8 billion in January, 1941. The ratio of excess reserves to net demand deposits rose from an average of about 4 per cent in 1933 to almost 20 per cent over 1940.^{10/} It is this truly unique event in our banking history--the growth to the extremely high level of excess reserves--which the many and varied ex post studies have focused upon. While some of the build-up of excess reserves can certainly be attributed to supply factors--e.g., a lagged reaction to gold inflows--some of the shift must also be due to the same desire for liquidity which apparently motivated the move toward investments. For the interested reader, some of the more prominent theories which have been advanced to explain the banks' preferences for liquidity and the subsequent increase in excess reserves are the "shock effect" hypothesis of Friedman and Schwartz [6], the "inertia effect" hypothesis of George Morrison [17], and the bank wealth maximizing model of Frost ([7], [8]). (Some other examples of the wide variety of models which have been advanced to explain the portfolio structure of commercial banks during both "normal", non-panic periods, and panic periods such as the thirties are given in [9], [10], [14].)

In this paper we are concerned with the view that apparently prevailed in the Federal Reserve System during the thirties. That view, succinctly stated, was that the excess reserves were redundant, serving no useful economic function. These reserves were primarily unnecessarily surplus funds held by banks, proving that money conditions were easy and that the economy was characterized by a lack of private demand for credit. The condition of the banking system was characterized as a sort of metastable equilibrium: additional funds obtained by banks were added to cash balances while additional demand for funds was met by drawing down those balances. The desired structure of bank asset portfolios was regarded as non unique, any disturbances to that structure going largely unanswered. For example, in 1936

the official view of the Federal Reserve was that the increase in excess reserves in that year was simply a reflection of the inflow of gold:

"These excess reserves have resulted almost entirely from the inflow of gold from abroad and not from the System's policy of encouraging full recovery through the creation and maintenance of easy money conditions"^{11/}

Earlier, in 1935, testimony by Governor Eccles during hearings held by the House Committee on Banking and Currency on the Banking Act of 1935 indicated this prevalent view that the monetary authority was powerless to influence the stock of money through effects on reserves. In response to a question as to the wisdom of increasing money in circulation by buying up bonds, Governor Eccles replied:

"Here is what would happen: . . . such action would simply increase the reserves of the banking system by the amount of government bonds . . . purchased with currency. The currency would go out . . . but . . . would immediately go into the banks and from the banks into the Federal Reserve banks . . . and you would just have additional reserves, additional excess reserves."^{12/}

Bankers and economists alike expressed the view that the level of deposits and, hence, the degree of utilization of reserves was determined by the demand for credit which was deemed to be insufficient during this period. The position of the American Bankers Association was that banks stood ready, willing, and able to make loans. The same position, from the point of view of economists, was expressed by Angell []:

"In a time of inactive demand for bank credit, with an enormous surplus of commercial bank reserves already being idle, it would not matter whether three billions [of Federal government and related securities] or thirty were purchased [by the Federal Reserve Banks]. The immediate effect on business would be zero . . . But if business and the demand for credit revive, then these open market operations . . . will provide a very real and very dangerous foundation for a severe credit inflation--again at the wrong time."^{13/}

Moreover, this view was explicitly presented publicly by the Board of Governors as justification for their decision to double reserve requirements in 1936-1937. This doubling of reserve requirements in three steps between August, 1936, and May, 1937, reduced excess reserves by \$3 billion and is the single most "active" decision taken by the Federal Reserve during this period.^{14/} Banks made little adjustment to their portfolios following the first increase in reserve requirements, but the composition of asset portfolios and market interest rates both changed after the second and third steps of the change in reserve requirements. Banks sold their short term securities and drew down their balances at correspondent banks. Treasury bill rates increased from 0.178 per cent in February, 1937, to 0.447 per cent March and did not fall to its pre-March level again until November, 1937. Excess reserves at member banks fell from about \$2.2 billion in February to about \$1.4 billion in March and continued to decline through August to \$750 million. In April of 1938, reserve requirements were lowered to the level of that before the change in May, 1937. From that point on, excess reserves climbed steadily.

This notion that excess reserves served no useful economic function and accumulated only because of insufficient credit demand carries with it the implication that commercial banks exhibited an absolute preference for liquidity. An alternative statement of this proposition is that at the prevailing low rates of

interest in the thirties, banks' demand curves for excess reserves had become perfectly elastic; correspondingly, their demand curves for loans and investments had become infinitely elastic.^{15/} This view, of course, is a characterization of the banking system being caught in a "liquidity trap". The major implication of this notion for the conduct of monetary policy was that the link between the authority's control over bank reserve positions and the control of the money supply was broken. This situation was likened to the inability of one to "push on a string", e.g., as Governor Eccles remarked,

"... one cannot push on a string. We are in the depths of a depression and, . . ., beyond creating an easy money situation through reduction of discount rates and through the creation of excess reserves, there is very little, if anything, that the reserve organization can do toward bringing about recovery."^{16/}

This widely held view of the financial sector was, therefore, a primary reason that the monetary authority took no decisive steps of any kind during the 1930's, electing instead to merely hold a fixed portfolio of government securities.^{17/} Unhappily, this notion which so pervaded the policy making process does not appear to have been based upon any rigorous model, but rather on somewhat casual observation.^{18/} The magnitude of excess reserves was taken as supportive of the liquidity trap hypothesis as was the correlation between changes in total reserves and in excess reserves during the decade. Also, taken as supportive of the liquidity trap was the apparent flattening out at low interest rates of the locus of points described by a plot of excess reserves versus a short term interest rate. Those who disagreed at that time with the "string" hypothesis seem to have based their conclusions on equally casual empiricism. It was pointed out that a plot of excess reserves versus $\log r_t$ failed to indicate a horizontal curve at low rates of interest.^{19/}

Econometric tests of the liquidity trap hypothesis have generally been conducted within the confines of particular models and have dealt with the derivation and/or estimation of asset demand functions. Tests for the existence of the liquidity trap have been reported as the estimation of demand curve elasticities ([9], [17]), the examination of correlations among interest rates and bank earning assets ([10], [17]), the comparison of goodness of fit among alternative relations and the examination for appropriate signs on various coefficients in estimated demand relations ([8], [17]). Such studies have produced models which differ not only as to primary determinants of, and motives for the holdings of various asset classes, but also as to the appropriate direction of causation in the relevant relationships.^{20/} Virtually all of these studies have failed to uncover strong evidence supporting the "string doctrine"; it is worth noting, however, that none of these studies has involved a direct test of the causal relations implied by the hypothesis.^{21/}

This investigation into the possible existence of a liquidity trap focuses on the causal relations which are implied by one interpretation of that hypothesis. The studies of this hypothesis which involve the estimation of a demand function have implicitly been based upon some notion of causality over time; this concept apparently has never been applied directly in connection with this problem. Because the word "cause" has so many varied interpretations, we must focus on a particular definition of causality. Furthermore, in a desire to maintain consistency, at least from the point of view of economic theory, with those studies which have centered upon demand relations, we note that in order to obtain consistent estimates of a demand relation the right hand side variables must be exogenous. With these thoughts in mind, we establish in the following section a definition of and a procedure for testing for the existence of a liquidity trap based upon the Granger [12] definition of causality in a multivariate framework.

II. A Version of the Liquidity Trap Hypothesis

In a general way, we are concerned here with the determinants of the composition of commercial bank portfolios; in particular, we are interested in the determinants of the excess reserve position of banks. Accordingly, we must concern ourselves not only with all assets in bank portfolios, but also with the role of variables such as interest rates, the money supply, and measures of business conditions and economic activity which might reflect demand for bank credit. Therefore, even though the formulation and estimation of the demand curve lies, in this study, within the realm of partial equilibrium analysis, our problem is clearly concerned with the ways in which the financial and real sectors of the economy interact. Demand analysis is first of all a formulation concerning the direction of effects, and secondly, an attempt at determining the quantitative effects of changes in the causal factors.

Consider briefly the following simplified balance sheets for the monetary authority and for the commercial banking sector:

FED		COMMERCIAL BANKS	
Gold Certificates	Treasury Deposits	Reserves (Required) (Excess)	Demand Deposits
U.S. Government Securities	Member Bank Reserves		Time Deposits
Discounts & Advances	Fed. Reserve Notes - Outstanding	U.S. Government Securities	Borrowings
Treasury Currency		Loans & Investments	Net Worth

Now a liquidity trap, in its simplest formulation, is simply the notion that at some rate of interest the demand curve for money becomes infinitely elastic. The corollary to this notion as applied to banks in the '30's decade was that interest rates had fallen to a level where banks' demand curve for excess reserves was infinitely elastic. Thus, any attempt by the monetary authority to increase the money supply or to foster an increase in bank credit outstanding was simply thwarted by banks' willingness to hold the additional reserves as functionless idle cash. The quantity of loans and investments at any time was viewed as being determined by forces beyond the control of the monetary authorities, primarily by the existing demand for credit by the non-banking public and business community. The basic notion behind the "string" hypothesis was, therefore, that the money supply (or, alternatively, outstanding demand and time deposits) and loans and investments in commercial bank portfolios were exogenous with respect to the portfolio of the monetary authority.

Following Horwich [14], let us define a series termed "effective reserves" which is essentially total bank reserves adjusted for all legal changes in the capacity to use those reserves. Now this notion of a breakdown in the more "normal" causal chain of effects running from reserve changes to the money supply and bank credit may be succinctly stated in the form of a directly testable hypothesis:

- (i) both the money supply and outstanding loans and investments were exogenous with respect to effective reserves, and
- (ii) excess reserves were not exogenous with respect to effective reserves.

The next section presents a discussion of the methodology of the statistical tests to be performed, utilizing the Granger[12] definition of causality and the equivalency of that definition with statistical exogeneity as established by Sims [24]. Before formulating our tests, however, we may find it instructive to digress briefly and to consider the study by Horwich.

A Digression on Horwich's Tests for the
Existence of a Liquidity Trap

This study is, to our knowledge, the only one which attempted a direct test of the causal implications of the liquidity trap hypothesis in the 1930's. It also appears to be the singular example of an investigative failure to strongly reject the string hypothesis. Horwich attempted to test what he termed the Keynesian view--the ineffectiveness of monetary policy in the determination of bank earning assets--versus what he termed the Wicksellian view--that bank earning assets and the money supply were causally related to reserves--by examination of the correlations between earning assets and effective reserves, and between their first and their second differences.

The 1930's were subdivided into four periods and quarterly call report data for member banks were used. In three of the four subperiods were found positive, though different, correlations between total earning assets and effective reserves, while in the period March, 1936 to June, 1938 (during this period reserve requirements were doubled in three steps), a significant negative correlation was observed. More important, in Horwich's view, than the positive correlations during the subperiods, was the extremely low correlation (0.04) between earning assets and effective reserves over the entire decade. The presence of a significant negative correlation in a period separating two periods between which the positive correlation appeared to have shifted considerably, and of a low correlation between second differences of earning assets and effective reserves were viewed as contradicting the Wicksellian hypothesis and, hence, supporting the string version of the liquidity trap hypothesis. It was speculated that specification error in the form of omitted variables may have biased the subperiod regressions showing

positive correlation toward verification of the Wicksellian view. In addition, over this decade, both total earning assets and bank loans were highly correlated with an adjusted personal income series (taken as a proxy for loan demand). Furthermore, it was found that bank holdings of government securities were more highly correlated with the total supply of such securities than with effective reserves, an observation which, under the assumption of an aggregate supply independent of bank demand, was interpreted as further evidence consistent with the Keynesian view.

Though his tests were deficient since correlation analysis, in general, implies nothing regarding the direction of causation, Horwich's basic idea of testing directly for the implications of the hypothesis was nonetheless a proper approach. Unfortunately, the analysis only points out the periods over which persisted certain correlations that are not, at least partially, inconsistent with the liquidity trap hypothesis. It is possible, however, as was realized by Horwich and others, that the correlations which were found could possibly exist even if the direction of causality were opposite that implied by his interpretation of the liquidity trap hypothesis. The information which may be garnered from the available data set, i.e., the important correlations which are observed, are contained in estimates of the reduced form. Macroeconomic models can be devised which, e.g., exhibit positive correlations between money and income, but which differ by virtue of the exogeneity in one case of money, and in another case, of income. In addition, it is possible to construct models in which money and income would be correlated via their mutual dependence on a third variable. An important point is that different structures, with different causal relationships, may

be summarized in observationally equivalent reduced forms which provide our only means of drawing inferences about the structure. Much more technical and complete discussions of these points may be found in Sims ([23], [24]) and in Sargent ([21], [22]).^{22/}

III. Testing the Liquidity Trap Hypothesis

The tests for existence of a liquidity trap in the 1930's take the form of econometric tests of the causal implications of our interpretation of that hypothesis within the confines of Granger's [12] particular definition of causality. The procedure derives from Sims' [24] important work, in which he established the equivalence between Granger causality and the econometrician's definition of statistical exogeneity.^{23/} Before proceeding to a discussion of the test procedure for the multivariate system with which we are concerned, let us briefly review the Granger definition and the construct of tests of causal ordering as implied by the theory for a bivariate universe.

Granger's definition of causality places a central role on the stochastic nature of the variables and on the direction of flow of time; " ... We say that Y_t is causing X_t if we are better able to predict X_t using all available [past] information than if the information apart from [past] Y_t had been used."^{24/} The better predictor is that which minimizes the variance of the forecast error. In the bivariate system described by the set $\{X_t, Y_t \mid t = 0, 1, \dots, T\}$, a direct test of the null hypothesis that Y fails to cause X in Granger's sense, is obtained via OLS estimation of

$$(1) \quad \hat{X}_t = \sum_{i=1}^p \hat{a}_i X_{t-i} + \sum_{i=1}^q \hat{b}_i Y_{t-i},$$

where \hat{X}_t is the least squares forecast of X_t based on the estimates (\hat{a}_i, \hat{b}_i) of the parameters (α_i, β_i) . The null hypothesis that $\beta_i = 0, i = 1, 2, \dots, q$, is thus directly testable through construction of F-statistic for (1) and a second regression in which the coefficients on lagged Y's are constrained to be zero.

Sims ([24], [25]) established the following equivalency to the preceding formulation: assuming that X and Y are jointly covariance-stationary stochastic processes and are jointly purely indeterministic, then the conditions that

- (i) Y fails to cause X in Granger's sense , and
- (ii) X is strictly exogenous relative to the residual from a linear regression of Y on current and past X

are equivalent. Furthermore, if the process [X Y]' possesses an autoregressive representation, i.e.,

$$(2) \quad \begin{aligned} (a) \quad X_t &= \sum_{i=0}^{\infty} a_i \epsilon_{t-i} + \sum_{i=0}^{\infty} b_i \eta_{t-i} \\ (b) \quad Y_t &= \sum_{i=0}^{\infty} c_i \epsilon_{t-i} + \sum_{i=0}^{\infty} d_i \eta_{t-i}, \end{aligned}$$

where ϵ and η are mutually uncorrelated white noise processes, then (i) above is equivalent to either ⁽ⁱⁱⁱ⁾ all $a_i = 0$ or all $b_i = 0$ in (2). Conditions (iii) and (ii) then imply that (i) taken as our hypothesis may be tested via the least squares regression,

$$Y_t = \sum_{i=-m}^m g_i X_{t-i} + e_t,$$

where e_t is the residual, and testing for the condition $g_i = 0$ for all $i < 0$.

The rationale behind our tests for the existence of a liquidity trap is clearly formulated in Sims [24]. Previous tests which took the form

of demand equation estimates, emphasizing the role of coefficient sign and magnitude determinations and elasticity estimates, yielded valid estimates only if the right hand side variables satisfied the requisite exogeneity assumptions. Accordingly, testing for the correctness of those assumptions and the equivalence with testing for Granger causality provides a natural way to approach this issue.

Most empirical work to date dealing with exogeneity considerations has been confined to bivariate and tri-variate systems. We are concerned here with the relationships which prevailed during the 1930's among at least the set of variables {excess reserves, reserves, loans and investments in bank portfolios, money supply}. As Horwich indicated, it is not difficult to see how some measure reflecting the level of business activity and the related demand for bank credit could be included in a statement of the liquidity trap hypothesis. In addition, as many investigators have noted, failure to allow for the influence of interest rates could easily distort test results.^{25/} What we must do is establish an appropriate testing procedure for the type of multivariate system in our problem. We present below a cursory discussion of the general considerations involved in tests for exogeneity in multivariate systems followed by the construction of some tests specific to our problem.^{26,27/}

Consider the n -element vector covariance-stationary stochastic process $X(t) = [X_1(t) X_2(t)]'$ where X_1 is of dimension n_1 , X_2 is of dimension n_2 , and $n_1 + n_2 = n$. It is well known that the "best", in the sense of minimum mean square error, linear predictor $\hat{X}(t)$ of the components of $X(t)$ by $X(s)$, $s < t$, is given by

$$\hat{X}(t) = \sum_{j=0}^{\infty} G(j)X(t-j)$$

so that

$$X(t) = \sum_{j=0}^{\infty} G(j)X(t-j) + U(t)$$

where $U(t)$ is the vector innovation process and where $E[X(s)U(t)'] = 0$ for all $s \leq t - 1$, $t = 0, \pm 1, \pm 2, \dots$. Rewriting the above we have

$$(3) \quad \sum_{s=0}^{\infty} B(s)X(t-s) = U(t)$$

where $B(0) = I_n$, the $n \times n$ identity matrix, and where $\sum_{k=0}^{\infty} B(k)[B(k)]' < \infty$. The covariance structure of U , where $E[U(t)U(t-p)'] = R_u(p)$, is given by $R_u(0) = I$, $R_u(p) = 0$ for all $p \neq 0$. (U is then termed a white-noise vector with components serially and mutually uncorrelated.) Since we deal with samples of finite length, the form of (3) with which we are generally concerned is given by

$$(3') \quad \sum_{s=0}^m B(s)X(t-s) = U(t)$$

with B and U satisfying conditions as above. Now as long as the roots of $\det(B(Z)) = 0$, where $B(Z)$ is $= \sum_{s=0}^m B(s)Z^s$, lie outside the unit circle, the solution to (3) is a one-sided vector moving average representation,

$$(4) \quad X(t) = \sum_{i=0}^{\infty} D(i)U(t-i)$$

where $D(0) = I_n$, $\sum_{i=0}^{\infty} D(i)[D(i)]' < \infty$.^{28/} The conditions on $\{X(t)\}$, the D 's, and on $\{U(t)\}$, together with (4) form a statement of the Wold Decomposition Theorem.^{29/}

Before considering explicitly our method for exogeneity testing, let us introduce some notation and some definitions. The convolution of a function f with a function g , written $f * g$, is a new function given by

$$f * g(t) = \sum_{k=-\infty}^{\infty} f(k)g(t-k)$$

where f and g may be matrix, vector, or scalar valued functions. We will be concerned with cases where $f(k) = 0$, $k < 0$. Denote $H(L)$ (or $h(L)$) to be a polynomial

$$H(L) = \sum_{k=0}^{\infty} H(k)L^k$$

$$(h(L) = \sum_{k=0}^{\infty} h(k)L^k)$$

where L is the lag operator $L^m Z_t \equiv Z_{t-m}$. We shall use these notations interchangeably.

Write the vector autoregression corresponding to (3)' for $X(t)$ ^{30/} as

$$(5) \quad \begin{bmatrix} B_{11} & B_{12} \\ B_{21} & B_{22} \end{bmatrix} * \begin{bmatrix} X_1 \\ X_2 \end{bmatrix} (t) = \begin{bmatrix} U_1 \\ U_2 \end{bmatrix} (t)$$

where B_{11} is $(n_1 \times n_1)$, B_{12} is $(n_1 \times n_2)$, B_{21} is $(n_2 \times n_1)$, B_{22} is $(n_2 \times n_2)$, and where X_1 and X_2 , U_1 and U_2 are conformable partitions of X and U , respectively.

The solution to (5), corresponding to (4), is

$$(6) \quad \begin{bmatrix} X_1 \\ X_2 \end{bmatrix} (t) = \begin{bmatrix} A_{11} & A_{12} \\ A_{21} & A_{22} \end{bmatrix} * \begin{bmatrix} U_1 \\ U_2 \end{bmatrix} (t)$$

with appropriately dimensioned partitions. We are concerned here with a notion of block exogeneity or causality, i.e., if in Granger's sense, X_2 is causing X_1 , without feedback from X_1 to X_2 , then either

$$(7a) \quad \begin{aligned} (B_{21})_{ij} &= 0, \quad i = 1, \dots, n_2; j = 1, \dots, n_1, \text{ or} \\ (B_{22})_{kl} &= 0, \quad k = 1, \dots, n_2; l = 1, \dots, n_2. \end{aligned}$$

By appeal to Theorem 1 in Sims [24], the equivalent condition in (6) is either

$$(7b) \quad \begin{aligned} (A_{21})_{ij} &= 0, \quad i = 1, \dots, n_2; j = 1, \dots, n_1, \text{ or} \\ (A_{22})_{kl} &= 0, \quad k = 1, \dots, n_2; l = 1, \dots, n_2. \end{aligned}$$

The notion is that all of the elements of X_2 are exogenous with respect to all of the elements of X_1 or, alternatively, all of the elements of X_1 fail to cause, in Granger's sense, any of the elements of X_2 .

One set of tests for this notion of block exogeneity is suggested by Granger's definition. Each of the n_2 elements of X_2 may be individually regressed against lagged values of all n_2 elements of X_2 (including itself). Then, regressions may be run including past values of the n_1 elements of X_1 ;

under the hypothesis (7a), these elements collectively (lagged values of all n_1 components) or singly (lagged values of each of the n_1 components alone) should have, as a group, coefficients not significantly different from zero.

Appeal to Theorem 2 in Sims yields a second set of tests. Each element of X_1 may be regressed against ^{future,} current, and lagged values of all elements of X_2 ; each relationship should then be tested for two-sidedness, i.e., future values of the components of X_2 should have, collectively, coefficients not significantly different from zero. However, even if (7) is true, the same results should ^{not necessarily} obtain if the test is performed pair-wise between elements of X_1 and X_2 .

In order to complete the set of tests of (7), the above procedures should be performed with the roles of X_1 and X_2 reversed. If (7) is in fact true, all of the tests should imply (7). Unfortunately, the implications of our tests may not resolve the issues so clearly. Validity of the tests is, of course, dependent upon the specified universe and it is always possible that our system may be mimicking some larger and more complicated structure. Particularly in cases where $n_1 \geq 2$, it is possible to obtain conflicting F-tests on future coefficients of X_2 components.^{31/} Unfortunately, I see no general, easy way to decide, when faced with conflicting results among both alternative forms of two-sidedness tests and alternative forms of Granger-type tests, how to go about resolving the conflicting pieces of evidence. The issues then boil down ^{to} which forms of the tests are most powerful, the discussion of which is beyond the scope

of this paper. The questions may, in some limited sense, be resolvable in specific cases by consideration of possible structures which could generate the types of results obtained, and by consequent suitable redefinition of the universe. The point is, and this should become clearer in the following discussion of our particular tests, that where results strongly support the hypothesis (7), we may indeed conclude that the evidence supports our investigation and consideration of models in which X_2 is block exogenous with respect to X_1 . The conditions under which our tests would support (7) seem to be far more stringent than the conditions which, e.g., might lead to two-sided distributed lags, particularly in a multivariate system. Thus, while evidence strongly, or even mildly supportive of (7) would have to be interpreted cautiously, it would seem that in those situations the burden might naturally fall on critics to construct reasonable alternative models in which the test results would be obtained as spurious results.

An important point, often overlooked, is that (6) is not a unique representation. Sims established the existence of at least one representation where Granger causality is equivalent to the exogeneity of one variable (or group of variables) with respect to another variable (or group of variables). There exist, however, a multiplicity of equivalent representations.^{32/} Consider (6) again,

$$(6') \quad X = A*U$$

where U is a white noise vector as before. The spectral density function

of X is given by $S_X(\omega) = \tilde{A} \tilde{A}'$, where \tilde{A} is the Fourier transform of A . Now premultiply U by any C and postmultiply A by C^{-1} . Now

$$(6'') \quad X = AC^{-1} * CU$$

but $S_X(\omega) = \tilde{A} \tilde{A}'$ again, so that the two representations are observationally equivalent. Furthermore, if C is orthogonal, the vector $U' = CU$ is still a serially uncorrelated vector with mutually uncorrelated components. C need not be orthogonal, however, to yield an alternative equivalent representation to (6). Note that, e.g., for (7) to hold, with our other original conditions intact, the vector $U(t) = [U_1(t) U_2(t)]'$ may have covariance structure which is block-diagonal, i.e.,

$$R_u(p) = 0, \quad p \neq 0$$

and

$$R_u(0) = \begin{bmatrix} \Sigma_1 & 0 \\ 0 & \Sigma_2 \end{bmatrix}$$

where $\Sigma_1 = R_{u_1}(0)$ and $\Sigma_2 = R_{u_2}(0)$. The tests for block exogeneity are then applicable as before. Causality-exogeneity tests are, therefore, tests on the search for a model or models among all possible models which is, or are, consistent with the correlations observed in the data and in which X_2 is interpreted as exogenous.

We desire to apply now the above procedures to our interpretation of the liquidity trap hypothesis given earlier. For the time being, let us concentrate on the four-variate system:

Z = effective reserves

X = excess reserves

m = money supply (or net demand and time deposits)

l = loans and investments in bank portfolios.

Write the autoregression for the vector $(X_t, Z_t, m_t, l_t)'$ as

$$(8) \begin{bmatrix} X_t \\ Z_t \\ m_t \\ l_t \end{bmatrix} = \begin{bmatrix} a & b & c & d \\ a' & f & g & h \\ a'' & b'' & p & q \\ a''' & b''' & r & s \end{bmatrix} * \begin{bmatrix} X_{t-1} \\ Z_{t-1} \\ m_{t-1} \\ l_{t-1} \end{bmatrix} + \begin{bmatrix} \eta_{1t} \\ \eta_{2t} \\ \eta_{3t} \\ \eta_{4t} \end{bmatrix}$$

Under our version of the liquidity trap (its existence will hereafter be our null hypothesis) all of the primed functions are identically 0 for all $s \neq t$. The vector $\eta_t = (\eta_{1t}, \eta_{2t}, \eta_{3t}, \eta_{4t})'$ is the vector innovation. Appealing to the theory discussed above, we may test for zero coefficients in this representation by direct application of the Granger tests. Furthermore, under the null hypothesis that $(m_t, l_t)'$ is exogenous with respect to $(X_t, Z_t)'$ without feedback from $(X_t, Z_t)'$ to $(m_t, l_t)'$, future coefficients in a regression of $(X_t, Z_t)'$ on $(m_t, l_t)'$ should be 0.

It is possible, as indicated above, to derive alternative equivalent representations to (8) and to test, within those representations, the null hypothesis. Note that

$$\eta_{1t} = X_t - a(L)X_{t-1} - b(L)Z_{t-1} - c(L)m_{t-1} - d(L)l_{t-1},$$

i.e., η_{1t} is a linear combination of current and lagged X , and lagged values of Z , m , and l . Now η_{1t} is the innovation, or error, in the prediction of current X from past (X , Z , m , l); η_{1t} is thus orthogonal to past values of those variables or

$$E(\eta_{1t} | X_{t-1}, X_{t-2}, \dots, Z_{t-1}, Z_{t-2}, \dots, m_{t-1}, m_{t-2}, \dots, l_{t-1}, l_{t-2}, \dots) = 0.$$

Similarly,

$$E(\eta_{1t-1} | X_{t-2}, X_{t-3}, \dots, Z_{t-2}, Z_{t-3}, \dots, m_{t-2}, m_{t-3}, \dots, l_{t-2}, l_{t-3}, \dots) = 0$$

and η_{1t-1} is a linear combination of those conditioning variables and X_{t-1} . It follows that $E(\eta_{1t} | \eta_{1t-1}) = 0$, i.e., that η_{1t} is serially uncorrelated. By similar reasoning for η_{jt} , $j = 2, 3, 4$, η_t is a serially uncorrelated ^{general} vector. It will not in/be true, however, that $R\eta(0) = I$, or even a scalar matrix. Assume

$$R_{\eta}(0) = E \begin{bmatrix} \eta_t^{(1)} \\ \eta_t^{(2)} \end{bmatrix} \begin{bmatrix} \eta_t^{(1)} \\ \eta_t^{(2)} \end{bmatrix}' = \begin{bmatrix} \Sigma_{11} & \Sigma_{12} \\ \Sigma_{21} & \Sigma_{22} \end{bmatrix}$$

where $\eta_t^{(1)} = (\eta_{1t} \ \eta_{2t})'$, $\eta_t^{(2)} = (\eta_{3t} \ \eta_{4t})'$. Define the correlation between $\eta_t^{(1)}$ and $\eta_t^{(2)}$ according to

$$\begin{bmatrix} \eta_{1t} \\ \eta_{2t} \end{bmatrix} = T \begin{bmatrix} \eta_{3t} \\ \eta_{4t} \end{bmatrix} + \begin{bmatrix} v_{1t} \\ v_{2t} \end{bmatrix} = \begin{bmatrix} t_{11} & t_{12} \\ t_{21} & t_{22} \end{bmatrix} \begin{bmatrix} \eta_{3t} \\ \eta_{4t} \end{bmatrix} + \begin{bmatrix} v_{1t} \\ v_{2t} \end{bmatrix}$$

where $E \begin{bmatrix} v_{1t} \\ v_{2t} \end{bmatrix} | \begin{bmatrix} \eta_{3t} \\ \eta_{4t} \end{bmatrix} = 0$, a 2x2 matrix, and where t_{ij} is the regression coefficient of η_{it} on $\eta_{j+2,t}$. Now applying the transformation

$$\begin{bmatrix} I_2 & -T \\ 0 & I_2 \end{bmatrix}$$

to both sides of (8) and rearranging terms we have, under the null hypothesis,

$$(9) \begin{bmatrix} X_t - t_{11}m_t - t_{12}l_t \\ Z_t - t_{21}m_t - t_{22}l_t \\ m_t \\ l_t \end{bmatrix} \begin{bmatrix} a(L) & b(L) & c(L) - t_{11}p(L) - t_{12}r(L) & d(L) - t_{11}q(L) - t_{12}s(L) \\ 0 & f(L) & g(L) - t_{21}p(L) - t_{22}r(L) & h(L) - t_{21}q(L) - t_{22}s(L) \\ 0 & 0 & p(L) & q(L) \\ 0 & 0 & r(L) & s(L) \end{bmatrix} \begin{bmatrix} X_{t-1} \\ Z_{t-1} \\ m_{t-1} \\ l_{t-1} \end{bmatrix} + \begin{bmatrix} v_{1t} \\ v_{2t} \\ \eta_{3t} \\ \eta_{4t} \end{bmatrix}$$

Note that under H_0 ,

$$\begin{bmatrix} m_t \\ l_t \end{bmatrix} = \begin{bmatrix} p(L) & q(L) \\ r(L) & s(L) \end{bmatrix} \begin{bmatrix} m_{t-1} \\ l_{t-1} \end{bmatrix} + \begin{bmatrix} \eta_{3t} \\ \eta_{4t} \end{bmatrix}$$

$$= F(L) \begin{bmatrix} m_{t-1} \\ l_{t-1} \end{bmatrix} + \begin{bmatrix} \eta_{3t} \\ \eta_{4t} \end{bmatrix}$$

or

$$[I - LF(L)] \begin{bmatrix} m_t \\ l_t \end{bmatrix} = \begin{bmatrix} \eta_{3t} \\ \eta_{4t} \end{bmatrix}$$

From this $(m_t, l_t)'$ lies in the space spanned by $(\eta_{3t}, \eta_{4t})'$ (and its history). Since $V_t = (v_{1t}, v_{2t})'$ is orthogonal to $\eta_t^{(2)}$, $E[V_t | (m_t, l_t)'] = 0$ and the first two equations in (9) may be consistently estimated. Accordingly, (9) is a representation in which H_0 holds, and in which current (m_t, l_t) enter into the determination of (X_t, Z_t) ; future (m_t, l_t) do not enter, however. These implications may be tested directly. Note that lagged X's still do not help determine Z_t , and note also that T will be consistently estimated. 33/

Consider now the decomposition of η_t in (8) according to the regressions:

$$\begin{aligned}\eta_{3t} &= \theta_1 \eta_{4t} + U_{3t} \\ \eta_{2t} &= \theta_2 U_{3t} + \theta_3 U_{4t} + U_{2t} \\ \eta_{1t} &= \theta_4 U_{2t} + \theta_5 U_{3t} + \theta_6 \eta_{4t} + U_{1t}\end{aligned}$$

so that

$$U(t) = \begin{bmatrix} U_{1t} \\ U_{2t} \\ U_{3t} \\ \eta_{4t} \end{bmatrix} = \begin{bmatrix} 1 & -\theta_4 & \theta'' & \theta' \\ 0 & 1 & -\theta_2 & \theta''' \\ 0 & 0 & 1 & -\theta_1 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \eta_{1t} \\ \eta_{2t} \\ \eta_{3t} \\ \eta_{4t} \end{bmatrix} = \Theta \eta(t)$$

where

$$\begin{aligned}\theta' &= \theta_3 \theta_4 - \theta_4 \theta_2 \theta_1 + \theta_5 \theta_1 - \theta_6 \\ \theta'' &= \theta_4 \theta_2 - \theta_5 \\ \theta''' &= \theta_2 \theta_1 - \theta_3.\end{aligned}$$

Now, rewrite (8), under H_0 , as

$$(8') \left\{ I_4 - L \begin{bmatrix} a(L) & b(L) & c(L) & d(L) \\ 0 & f(L) & g(L) & H(L) \\ 0 & 0 & p(L) & q(L) \\ 0 & 0 & r(L) & S(L) \end{bmatrix} \right\} \begin{bmatrix} X \\ Z \\ m \\ \ell \end{bmatrix} (t) = \eta(t).$$

or

$$[I - LH(L)] [X Z m \ell]'(t) = \eta(t).$$

Applying the transformation Θ to both sides of (8'), we see

$$(10) \quad \Omega(L) \begin{bmatrix} X \\ Z \\ m \\ l \end{bmatrix} (\tau) = \begin{bmatrix} U_1 \\ U_2 \\ U_3 \\ U_4 \end{bmatrix} (\tau)$$

where $\Omega(L) = [\Theta - \Theta LH(L)]$. Noting that Θ is upper triangular and that $\Theta LH(L)$ has all elements in its SW corner $0/H_0$ (along with the $(2,1)^{th}$ element), we see that we have arrived at a particular Wold representation for the system.^{34/} By inspection of $\Omega(L)$, we see that under H_0 the predictors of l_t , M_t , Z_t , X_t in this representation are given by the regressions

$$(11) \quad \begin{aligned} & E(l_t | M_{t-1}, M_{t-2}, \dots, l_{t-1}, l_{t-2}, \dots) \\ & E(M_t | l_t, M_{t-1}, M_{t-2}, \dots, l_{t-1}, l_{t-2}, \dots) \\ & E(Z_t | M_t, l_t, Z_{t-1}, Z_{t-2}, \dots, M_{t-1}, M_{t-2}, \dots, l_{t-1}, l_{t-2}, \dots) \\ & E(X_t | Z_t, M_t, l_t, Z_{t-1}, Z_{t-2}, \dots, M_{t-1}, M_{t-2}, \dots, l_{t-1}, l_{t-2}, \dots, X_{t-1}, X_{t-2}, \dots). \end{aligned}$$

We may consider briefly one other alternative representation. From (8) we may get

$$(12) \quad \begin{aligned} X_t - Z_t = & [a(L) - a'(L)]X_{t-1} + [b(L) - b'(L)]Z_{t-1} + [c(L) - g(L)]M_{t-1} \\ & + [d(L) - h(L)]l_{t-1} + (\eta_{1t} - \eta_{2t}) \end{aligned}$$

$$\begin{aligned} M_t - l_t = & [a''(L) - a'''(L)]X_{t-1} + [b''(L) - b'''(L)]Z_{t-1} + [p(L) - r(L)]M_{t-1} \\ & + [q(L) - s(L)]l_{t-1} + (\eta_{3t} - \eta_{4t}) \end{aligned}$$

Decompose $(\eta_{1t} - \eta_{2t})$ according to the regression

$$(\eta_{1t} - \eta_{2t}) = \psi(\eta_{3t} - \eta_{4t}) + W_t$$

where $E(W_t | \eta_{3t} - \eta_{4t}) = 0$. Applying the transformation

$$\begin{bmatrix} 1 & -\psi \\ 0 & 1 \end{bmatrix}$$

to both sides of (12) we have, under H_0 ,

$$(13) \begin{bmatrix} (X_t - Z_t) - \psi(M_t - \ell_t) \\ M_t - \ell_t \end{bmatrix} = \begin{bmatrix} a(L)[b(L) - f(L)]c(L) - g(L) - \psi[p(L) - r(L)] & d(L) - h(L) - \psi[q(L) - s(L)] \\ 0 & 0 & p(L) - r(L) & q(L) - s(L) \end{bmatrix} \begin{bmatrix} X_{t-1} \\ Z_{t-1} \\ M_{t-1} \\ \ell_{t-1} \end{bmatrix} + \begin{bmatrix} W_t \\ \eta_{3t} - \eta_{4t} \end{bmatrix}$$

The results here are, of course, a transformation of (9). The tests are equivalent.

Now consider subsets of the relevant information set, in particular, $\{X_t, Z_t, M_t\}$. We might do this because our model does not include, in this case, loans and investments ℓ_t or because we perhaps question the underlying nature of the (M_t, ℓ_t) relationship justifying their joint inclusion in (8).

Write the revised system as

$$(14) \begin{bmatrix} X \\ Z \\ M \end{bmatrix} (t) = \begin{bmatrix} a(L) & b(L) & c(L) & X \\ a'(L) & d(L) & e(L) & Z \\ a''(L) & b''(L) & f(L) & M \end{bmatrix} (t-1) + \begin{bmatrix} \xi_1 \\ \xi_2 \\ \xi_3 \end{bmatrix} (t)$$

where again H_0 is indicated by the primed polynomials being identically zero. We might consider (14) in its entirety and apply the Granger and Sims tests directly. If, in fact, $\{\xi_t\}$ does not belong in the specification, then our tests may yield valid estimates. Of course, if $\{\xi_t\}$ or the sequence of observations on some other variable properly belong in (14) or (8), then our procedures may lead to erroneous inferences. For instance, if some missing variable is causing both M and X and/or Z, our tests may well fail to suggest that M is exogenous with respect to (X, Z).

Consider at least one alternative approach to the Sims - Granger tests on (14). Decompose ξ_{2t} and ξ_{1t} as in the four-variate system:

$$\begin{aligned} \xi_{2t} &= \varphi_1 \xi_{3t} + v_{2t} \\ \xi_{1t} &= \varphi_2 v_{2t} + \varphi_3 \xi_{3t} + v_{1t} \end{aligned}$$

where $E(v_{2t} | \xi_{3t}) = 0$, $E(v_{1t} | v_{2t}, \xi_{3t}) = 0$, and φ_1 , φ_2 , and φ_3 are the regression coefficients. Applying the transformation ϕ given by

$$\begin{bmatrix} 1 & -\varphi_2 & \varphi_1 \\ 0 & 1 & -\varphi_1 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \xi_{1t} \\ \xi_{2t} \\ \xi_{3t} \end{bmatrix} = \phi \xi(t) = v(t) = \begin{bmatrix} v_{1t} \\ v_{2t} \\ \xi_{3t} \end{bmatrix}$$

to both sides of (14), we obtain

$$(16) \begin{bmatrix} X_t \\ Z_t \\ M_t \end{bmatrix} = \begin{bmatrix} \varphi_2 Z_t - \varphi'_1 M_t + a(L)X_{t-1} + [b(L) - \varphi_2 d(L)]Z_{t-1} + [c(L) - \varphi_2 e(L) + \varphi'_1 f(L)]M_{t-1} \\ \varphi_1 M_t \\ +d(L)Z_{t-1} + [e(L) - \varphi_1 \bar{f}(L)]M_{t-1} \\ f(L)M_{t-1} \end{bmatrix} + \begin{bmatrix} V_{1t} \\ V_{2t} \\ \xi_{3t} \end{bmatrix}$$

where $\varphi' = \varphi_2 \varphi_1 - \varphi_3$.^{35/} This representation should be compared to (10) - (11).

What we have done is to indicate not only the ways in which the Sims - Granger causality test may be applied to a multivariate system but also, for our interpretation of the liquidity trap hypothesis, some alternative representations of the system in which the liquidity trap causal relations actually hold, although they may not appear to hold in estimated representations. We have been asking whether or not we could find a model or models consistent with the correlations in the 1930's data and in which the conditions (i) and/or (ii) in Section II are valid. If the data support any such model, then we are not justified in rejecting the liquidity trap as an explanation for the events of the 1930's or in pursuing the investigation of models which presume the existence of a liquidity trap.

It is important to note that in all of this, as Sims [23] has clearly pointed out, tests of exogeneity in terms of representations like (9), (11), (13), and (16) are, in general, weaker tests than are the two-sided or the Granger-type tests. What we are basically considering is a test of the notion an unconstrained estimate of (5) or that some transformation of (6) exists in which X_2 may be interpreted as exogenous with respect to X_1 . Our specific tests boil down to examining very particular representations which are equivalent to (6). Forms such as (9), (11), etc. do not have the appearance of Granger's "simple causal system"

and, as such, might not lead one to conclude, if, e.g., one were to begin by estimating (9) or (16), that X_2 is exogenous with respect to X_1 , even though the condition holds. Given our approach, beginning with forms of (6) such as (8) or (14), we may claim, if we do find that estimates of representations such as (9) and (16) are consistent with the null hypothesis, that we have found justification for interpreting X_2 as exogenous with respect to X_1 . On the other hand, failures of (9), (13), or (16) to appear consistent with H_0 do not necessarily imply that models with X_2 exogenous can not be found. Hence, the two-sided and Granger-type tests are both more convenient and in general, more powerful than are our particular alternative tests.

IV. Empirical Study

A. Comments on the Data

The data used in this study are all seasonally unadjusted figures in millions of dollars. The data were obtained from various publications of the Federal Reserve System.^{36/} The data are broken down by classes of banks, and tests for the existence of a liquidity trap are reported for four classes: (a) all banks which are members of the Federal Reserve System, (b) New York Reserve City banks, (c) Reserve City banks other than New York and Chicago Reserve City banks, and (d) country banks. Our earlier discussion of the liquidity trap was formulated in terms of the money supply. Net demand and time deposits subject to reserve requirements are used to proxy for this variable for each bank class.

B. Comments on Methodology

The data used in this study for each bank class are excess reserves (X), net demand plus time deposits subject to reserve requirements (D), and effective reserves (Z), which are total reserves adjusted for changes in reserve requirements.

The data used in the study are all used in level form with the sample mean and a linear trend removed. In addition, a deterministic seasonal pattern is removed from each series via least squares regression.

The results reported are based on two estimation procedures: ordinary least squares (OLS) and the Hannan efficient (HE) procedure.^{37/} The OLS procedure is used for the Granger-causality test via vector autoregression. The length of the estimated lag distribution was determined according to four criteria: (a) whiteness of the residual vector,

as determined by inspection of the cumulative periodogram of residuals and the Durbin-Watson (DW) statistic, (b) the point where additional lags had coefficients not statistically significantly different from zero as a group (F-test), (c) the point where the coefficients became small in absolute value, and (d) the number of degrees of freedom left as the lag length was changed.

For the HE procedure to be even approximately valid, the first stage residual vector must be as nearly white as possible. Therefore, for the Sims-exogeneity tests, each variable was prefiltered with the same filter and the residual vector from each equation in the vector autoregression was examined in both the time and frequency domains. A search was made over first-order filters from $(1-0L)$ to $(1-.9L)$ and over second-order filters from $(1-0L)^2$ to $(1-.9L)^2$ in steps of $0.1L$. The prefilter selected was based on DW statistic for assessing first-order serial correlation and on the Kolmogorov-Smirnov (KS) statistic based on the cumulative periodogram of the residuals for higher than first-order serial correlation.^{38/}

The HE procedure was implemented according to the following scheme. The periodogram of the first stage residual vector was obtained via the Fast Fourier Transform algorithm. The spectrum was estimated by smoothing the estimated periodogram using a triangular shaped window. The width of the window was determined roughly by examining the covariogram of the residuals obtained by inverse Fourier-transforming the periodogram of the residuals. For the regressions reported, the window varied from about $\pi/5$ to $\pi/9$ for the first period and from about $\pi/11$ to $\pi/18$ for the second period. The square root of the estimated spectrum was then

divided into the Fourier transforms of X, D, and Z at each frequency point. The resultant series were inverse-Fourier transformed and the new series used for the Sims-exogeneity tests.

C. Empirical Results

1. All Member Banks

The sample period, January 1929-December 1941, has been divided into two parts at the end of March 1933. This break point was chosen to coincide with the end of the banking holiday of 1933. It was at this time that the unprecedented growth in the level of excess reserves really seems to have begun. The pre-April 1933 period is then used as a sort of benchmark period against which to compare our results for the period during which a liquidity trap is posited to have existed.

Table 1A presents the results of the Granger-causality tests for the trivariate system $(X, D, Z)'$. The F-statistics at the bottom of the table test for nonzero coefficients on all lags of the nondependent variables, all lags of the first nondependent variable, and all lags of the second nondependent variable, respectively. In addition, the KS statistic is shown and in no case can we reject residual whiteness at even the 0.20 level of significance.

Table 1B shows the results of the HE estimates for the Sims-exogeneity tests over exactly the same period as covered by the estimates in Table 1A. In addition to the usual F-statistics, those testing for feedback to all future lags and the future lags on each variable separately are shown.

For this first period, the results for the two types of tests are entirely consistent. The Granger-causality tests indicate no single

variable, in the trivariate system, nor any pair of variables Granger-caused any third variable. Similarly, the Sims-exogeneity tests imply that we cannot reject the absence of feedback from any of the three variables to two other variables, either singly or together.

In short, based on the F-statistics and on the sizes of the coefficients on leads, the data appear to be consistent with the notion that each of the three variables in question fails to be Granger-caused by the other two, singly or collectively, within the trivariate system.

Tables 2A and 2B present the results of analogous tests for member bank data for the period following the banking holiday. In Table 2A are seen results which are suggestive of failing to reject absence of Granger-causality in this system. Excess reserves appear to be Granger-caused by effective reserves and deposits collectively at only about the 0.24 level. However, we can reject absence of Granger-causality from effective reserves to excess reserves at the 0.15 level and from deposits to excess reserves at the 0.17 level. Although these results provide what may be considered as only mild evidence for rejecting the absence of Granger-causality, they are suggestive.

Surprisingly, we may reject absence of Granger-causality from effective reserves and excess reserves to deposits at the 0.05 level. Even more surprising, we reject zero coefficients on X at the 0.13 level. The weakest evidence against no Granger-causality appears in the regression with effective reserves at the dependent variable. Here we may reject no Granger-causality at only the 0.34 level jointly and at the 0.28 and 0.22 levels for excess reserves and deposits, respectively.

In summary, the tests for Granger-causality over the second period are partially consistent with our version of the liquidity trap.

The data do appear to be consistent with Granger-causality running from effective reserves to excess reserves. However, deposits also appear to be Granger-caused by effective reserves and by excess reserves, contrary to our hypothesis.

Table 2B shows the results of the Sims-exogeneity tests over the same sample period. Surprisingly, and disturbingly, the results of these tests are not at all consistent with those of the Granger-causality tests. In all tests reported in Table 2B, the largest and by far most significant coefficients are the ones on current variables. In all cases we can reject feedback at very high significance levels. Furthermore, in all cases, coefficients on future variables are small. Thus, these tests are consistent with finding each of the three variables statistically exogenous with respect to each of the others and both of the others together in this trivariate system.

The reasons behind these visible contradictions between test results are not at all clear. Seasonality in the data may be one contributory factor. Except for removal of a deterministic pattern with dummies, seasonality has not been treated, partly to conserve degrees of freedom in these small samples. Possibly, the Granger-causality autoregressions have not been made long enough to unscramble the seasonal effects present. Alternatively, distortions at the ends of the sample period in the Fourier-transforms may be biasing the Sims-exogeneity tests. The most puzzling aspect of the different results, however, are the magnitudes of the difference. Essentially, the tests are presenting polar results, leaving completely unresolved the question of the existence of a liquidity trap.

2. New York Reserve City Banks

Tables 3A through 4B present the results of Granger-causality and Sims-exogeneity tests for New York Reserve City banks over the two periods. For the first period, the two types of tests are again consistent, implying both pairwise and singular absence of Granger-causality for all configurations of the trivariate system. Similarly, the Sims-exogeneity tests are consistent with the absence of feedback from each variable to either or both other variables.

Unlike the results for all member banks, the Granger-causality and Sims-exogeneity tests again both show no causality, no feedback in the second period for this class of banks. The closest we come to not rejecting absence of Granger-causality is for total deposits and effective reserves together; in this case, all coefficients are significantly different from zero at the 0.34 level.

In summary, the results for the New York Reserve City banks are rather uninteresting, implying no Granger-causality or, alternatively, exogeneity of all three variates over both sample periods. The results do suggest that for these banks, the period following the banking holiday was not characterized by a structural change in the management of financial assets, at least as far as these tests imply that sort of change.

3. Other Reserve City Banks

The results of the tests for this class of banks are presented in Tables 5A through 6B. For the first period, the results are basically identical to those of the previous bank classes studied. No Granger-causality was found among any pairs or blocks of the variables. The Sims-exogeneity tests likewise showed no signs of feedback in any direction.

The results in Tables 6A and 6B are somewhat more interesting than our results to this point. According to the Granger-causality tests, there is no really strong evidence against the absence of Granger-causality anywhere in the system. However, some rather weak evidence, suggesting that we might not want to reject out-of-hand Granger-causality running from effective reserves to excess reserves is given by an F-statistic significant at the 0.25 level. Similarly, in the Sims-exogeneity tests, we cannot in general reject absence of feedback from effective reserves to the other variables. However, the F-statistic for feedback from Z to X alone is significant at the 0.27 level.

Additionally, deposits appear to be not Granger-caused by either of the other variables, singly or together. The Sims-exogeneity tests show no feedback from either X or Z to D, whether D is considered jointly with another variable or alone. However, at the 0.08 level we cannot reject feedback from D to X and Z together nor from D to Z alone at the 0.07 level. Furthermore, the coefficients on leads in this regression are all large. Although the evidence is not overwhelming in favor of not rejecting the liquidity trap for this class of banks, the data are broadly consistent with our formulation of the trap.

4. Country Banks

The final class of banks investigated is the class of country banks. The results of the tests are shown in Tables 7A through 8B. Again, for the first period both tests are consistent with each other and with the absence of any pattern of Granger-causality.

The results for period two are as puzzling as those for member banks, but in the reverse direction. The tests for Granger-causality are consistent with the absence of causality in any pattern. The Sims-

exogeneity tests, on the other hand, show feedback in every direction. Future coefficients in a regression of X on D and Z are, for the two together, statistically significant at the 0.09 level. Singly, they are significant at the 0.05 and 0.07 levels, respectively. These coefficients are also large, relative to all other coefficients except those on current D and Z.

Similarly, in a regression of Z on X and D, future coefficients are significant at the 0.09 level together and at the 0.07 level individually. With D as the dependent variable, future coefficients are significant as a group at the 0.35 level, but the two groups separately are significant at the 0.11 and 0.12 levels.

These results are every bit as unexpected as those for member banks. We can, under either test, reject our version of the liquidity trap. However, the two tests lead to very different interpretations of the relationships in the trivariate system.

V. Summary and Conclusions

Granger-causality tests and, equivalently, Sims-exogeneity tests have been carried out to investigate the existence of a liquidity trap in the commercial banking sector in the 1930s. The results are not terribly definitive and, in fact, raise more questions than they answer.

For the period prior to the banking holiday, both sorts of tests for each class of banks studied are consistent with the absence of any pattern of Granger-causality. Thus, the data are consistent with exogeneity of all three variables in that period.

For the period following the banking holiday, the results are mixed and unclear. For New York Reserve City banks, both types of tests

suggest no change in the absence of causal patterns after the banking holiday. For other Reserve City banks, the data provide only moderate evidence against the absence of a liquidity trap. This class is the one case for which our data are, in a very broad sense, consistent with our notion of a liquidity trap. For member banks and for country banks the results are puzzling. The two types of tests are not consistent with each other and leave us unable to make any logical interpretation of the results at this time.

FOOTNOTES

1/ See, e.g., Phillips [18], quoted in Morrison [17], pp. 1-2.

2/ Friedman and Schwartz [6], Ch.6.

3/ See Phillips, op.cit., and Crick [5], both quoted in Morrison [17], Ch. .

4/ See Keynes [15], p.53.

5/ Ibid.

6/ Goldenweiser [11], quoted in Morrison [17], p.3.

7/ A classic treatment of these issues as they were viewed then is given in Riefler [19], who argues mainly that commercial banks (almost) never borrowed in an attempt to make profits but rather only when they were forced to, due to perhaps unexpected cash flow problems.

8/ Friedman and Schwartz, Table 17, p.450.

9/ Op cit, p.457.

10/ Frost [7], Graph 5-1, p.200.

11/ Twenty-third Annual Report, p.216, quoted in Morrison [17], p.25.

12/ U.S., Congress, House, Committee on Banking and Currency, Hearings on H.R. 5357, Banking Act of 1935, 74th Cong., 1st Session, p. 321; quoted in Morrison [17], p.25.

13/ Quoted in Morrison [17], p.26.

14/ Although this reason was the only one given publicly for the decision to double reserve requirements, in fact four other technical reasons lay behind their decision. These other reasons reinforce the notion that the Federal Reserve was completely unconcerned with the total money stock but rather was concerned with "credit" conditions- i.e., the market for loans and investments. See Friedman and Schwartz [6], Ch.9, Sec. 4, and the references cited therein.

15/ Op cit, pp.517-534.

16/ U.S. Congress, House, Committee on Banking and Currency, Hearings on H.R. 5357, Banking Act of 1935, 74th Congress, 1st Session, 1935, p. 377; quoted in Morrison [17], p.5.

17/ Friedman and Schwartz, loc cit.

18/ This comment should not be construed so as to imply that the liquidity trap is inconsistent with the more standard hypotheses underlying money demand models. In fact, as Morrison [17] shows, this passivity on the part of banks can definitely be placed in the usual framework relating money holdings to the "Keynesian" motives: transactions demand, speculative demand, and precautionary demand.

FOOTNOTES

19/ Many of these studies are alluded to in Frost [7] and in Morrison [17].

20/ For instance, Goldfeld and Kane ([10] treat borrowings as a function of an interest rate differential, past borrowings, and current and past changes in unborrowed reserves. Riefler [19] and Burgess [4], however, reversed the direction of causation, treating interest rates as a function of borrowings.

21/ The effort by Horwich [14] is the most noteworthy exception to this observation. Not only did he conclude that the data were in fact consistent with the string hypothesis but also his treatment of the problem came close to being a formulation of a direct test of the hypothesis.

22/ In addition, Brainard and Tobin [3] and Tobin [26] illustrate the pitfalls in attempting to establish a causal ordering through investigation of the temporal turning points of economic time series.

23/ Granger, op. cit.

24/ Sims also discusses this correspondence at greater length than in his AER article, using language less compact than that of Hilbert spaces, in a set of unpublished mimeographed notes [25]. In addition, Sargent (see, e.g. []) has also referenced this point and considered the ways in which proper tests may be implemented.

25/ The studies by Morrison [17] and by Frost [7], [8]), who considered a simple bank wealth maximizing model, provide examples of models which imply some measure of the interest rate as an important variable in the system.

26/ It has come to my attention too late to be employed efficiently in this draft that Sims has produced a far more technical, rigorous, and exhaustive discussion of the relevant issues than I have presented. The interested reader is referred to [23].

27/ The theory summarized here is developed extensively, using for the most part the language of Hilbert spaces, in Anderson [1] and in Hannon [11]. (A good background on Hilbert spaces may be found in e.g., Ash [2], especially Ch. 3.) An excellent though somewhat cryptic discussion may be found in Whittle [27]. Koopmans [16] provides a perhaps less technical but more readable treatment than the other sources for the univariate case.

FOOTNOTES

28/ Note that an additional condition for (4) to be the moving average representation for X is that U be a linear transformation of the limiting forecast errors for X (X purely linearly nondeterministic) as more and more past values of X are used in predicting future X. See, e.g., Sims [25].

29/ See Anderson [1], Ch. 7, for a statement of and proof of the theorem.

30/ We assume the conditions for existence of the vector autoregression are met.

31/ This possibility is easily seen in even a tri-variate system; more will be said of this type of situation when we discuss below our tests of the liquidity trap hypothesis.

32/ Hannan [13] presents a general statement of the vector Wold Decomposition Theorem where $R_U(t-s) = \delta_{ts} G$, δ_{ts} being the Kronecker delta and thus $X(t) = \sum_{s=0}^{\infty} A(s) U(t-s)$ where $\sum_{s=0}^{\infty} A(s) G[A(s)]' < \infty$.

33/ Alternatively, we could decompose $\eta_t^{(2)}$ according to $\eta_t^{(2)} = R \eta_t^{(1)} + U_t$. Under H_0 we would then have

$$\begin{bmatrix} X_t \\ Z_t \\ M_t \\ \ell_t \end{bmatrix} = \begin{bmatrix} a(L)X_{t-1} + b(L)Z_{t-1} + c(L)M_{t-1} + d(L)\ell_{t-1} \\ f(L)Z_{t-1} + g(L)M_{t-1} + h(L)\ell_{t-1} \\ R_{11}X_t + R_{12}Z_t \\ R_{21}X_t + R_{22}Z_t \end{bmatrix} + \begin{bmatrix} \eta_{1t} \\ \eta_{2t} \\ U_{1t} \\ U_{2t} \end{bmatrix}$$

where $PR(L) = p(L) - R_{11}c(L) - R_{12}d(L)$, $WR(L) = q(L) - R_{12}c(L) - R_{22}d(L)$, and $RR(L) = r(L) - R_{21}g(L) - R_{22}h(L)$, $SR(L) = s(L) - R_{21}g(L) - R_{22}h(L)$. Here lagged (X,Z) do not help determine (M,ℓ) but current (X,Z) do. No X's (future, current, or lagged) help determine Z.

34/ To see that U(t) in (10) has covariance structure $R_U(0) = I$ (or a scalar matrix), $R_U(s) = 0$, $s \neq 0$, proceed as in the previous case. $E(U_{3t} | \eta_{4t}) = 0$ by construction. Since η_{4t} is a linear combination involving ℓ_t , U_{3t} is orthogonal to ℓ_t . Therefore the third and fourth equations may be estimated consistently and the disturbances are uncorrelated. To actually obtain the Wold representation, the conditions necessary for the one-sided inverses to exist must be met.

35/ As before, under suitable conditions (14) can be rearranged to yield a Wold representation.

36/ See Banking and Monetary Statistics, 1914-1941, and various issues of the Federal Reserve Bulletin. I am grateful to Peter Frost for providing me with many of the time series used in this study.

37/ See Hannan (1970).

38/ See Lindgren (1968).

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