



## The Effects of Money Growth on Inflation and Interest Rates Across Spectral Frequency Bands

Mark A. Thoma

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MARK A. THOMA

## The Effects of Money Growth on Inflation and Interest Rates across Spectral Frequency Bands

THE EXISTENCE OF A CAUSAL RELATIONSHIP between changes in money growth and changes in both the inflation rate and the nominal interest rate is generally acknowledged. However, less agreement exists on the timing and magnitude of the response of inflation and the nominal interest rate to money shocks. Many economists believe that a positive shock to money growth brings about two opposing effects on the nominal interest rate. The first, known as the liquidity effect, is the fall in the nominal interest rate necessary to induce agents to hold additional real money balances. The second, known as the anticipated inflation effect, is the rise in the nominal interest rate due to the increase in expected inflation brought about by the increase in money growth. In the short run, it is often argued that the liquidity effect dominates the anticipated inflation effect. There is less agreement on the long-run effect of money shocks on interest rates. The time period required for the inflation resulting from money growth shocks to be fully realized, and whether the nominal interest rate moves one to one with expected inflation, are both unsettled questions that have stimulated a considerable body of research.<sup>1</sup>

The effect of money shocks on prices is less controversial than the effect of money on interest rates. An increase in money growth increases aggregate demand and brings about an increase in inflation. However, the magnitude and timing of the effects is open to question. Models featuring errors in forecasting prices or inflation typically assume that money growth shocks have a fairly immediate effect on prices,

1. Notable papers include Fisher (1930), Friedman (1968), Cagan (1963, 1972), Friedman and Schwartz (1963), Gibson and Kaufman (1968), Cagan and Gandolfi (1969), Gibson (1970), Stokes and Neuberger (1979), Summers (1983), Melvin (1983), Mishkin (1983), Stokes (1983), Geweke (1984), Cochran (1989), Romer and Romer (1989), and Christiano (1991).

while Keynesian and New Keynesian models assume that the effects of money growth shocks on inflation take much longer to be fully realized, particularly models where prices adjust sluggishly due to menu costs, S-s pricing rules, the PAYM insight, time dependent pricing rules, or imperfect competition.<sup>2</sup>

Though work on the relationship between money growth, inflation, and the nominal interest rate is generally conducted in the time domain, some authors have used frequency domain techniques to examine these relationships. Lucas (1980) and Summers (1983) use spectral filtering procedures to examine the neutrality of money and the Fisher hypothesis. Whiteman (1984) demonstrates that the frequency domain procedures used by Lucas and Summers can outperform time domain tests involving sums of distributed lag coefficients. Geweke (1982, 1984) expands upon the notion of Granger causality and shows how to measure the short-term or long-term relationship between time series by their feedback within a frequency band. Cochran (1989) shows that the liquidity effect dominates the anticipated inflation effect in the short run, that money growth and interest rates are negatively related in the short run, and provides a compelling argument for the use of band spectral filtering procedures to examine the relationship between money, prices, and interest rates.

The papers discussed in the preceding paragraph document the usefulness of spectral filtering procedures for examining the dynamic relationship between time series. This paper uses band spectral regression techniques to examine the dynamic properties of the responses of inflation and interest rates to money shocks. The procedure identifies the frequency movements that are most important in the relationships between money growth and inflation, and between money growth and nominal interest rates. In doing so, it provides answers to questions about whether high- or low-frequency movements in money growth cause movements in inflation and the nominal interest rate, and whether the movements caused are themselves of high or low frequency.

In an earlier paper, Thoma (1992) examines the dynamic response of output to money shocks and finds that relatively low- (eighteen months or longer) frequency movements in money growth cause similarly low-frequency movements in industrial production. This result is inconsistent with the new classical view that relatively high-frequency temporary shocks to money growth are the source of lower-frequency cyclical movements in output. This paper extends the investigation to inflation and the nominal interest rate. The techniques used in this paper reveal that cycles in the growth rate of M1 from one to two years long produce higher-frequency cycles in inflation, and two distinct sets of higher-frequency cycles in changes in the nominal interest rate.<sup>3</sup> The timing of these cycles corresponds closely to the timing of the liquidity effect and the anticipated inflation effect identified in

2. For a discussion of these models, see the survey by Fischer (1988). Empirical and theoretical references on these issues are extensive. Notable papers and sources of additional references include Cagan (1963), Lucas (1972), Barro (1978), Barro and Rush (1980), Okun (1981), Geweke (1982), Blanchard (1988), and Friedman and Kuttner (1992).

3. The change in the nominal interest rate rather than the level is used in the empirical model because, as Stock and Watson (1989) show, the level of the nominal interest rate contains a unit root.

previous research. This result, which is derived from a vector autoregressive (VAR) model incorporating reduced-form relationships, is consistent with a variety of Keynesian and new Keynesian models capable of producing the liquidity and anticipated inflation effects. However, the result that relatively low-frequency movements in money growth, movements that Lucas (1980) terms predictable, cause the movements in the interest rate appears inconsistent with models where forecast errors are the source of the liquidity and anticipated inflation effects. This conclusion is robust to dropping output from the empirical model and to measuring money as M2.

The paper begins by obtaining baseline money-inflation and money-interest rate causality results. Then, band spectrum regression techniques similar to Engle (1974, 1978) are used to remove particular frequencies from money growth, inflation, and the change in the interest rate. After removing the frequencies, money-inflation and money-interest rate causality tests are repeated and any changes in the money-inflation and money-interest rate causality statistics relative to the baseline results are noted. If the excluded frequencies are responsible for the baseline results, there should be a drop in significance relative to the baseline results. Conversely, if the excluded frequencies are unrelated to the causality results, then removing this noise from the system through the filtering of particular frequencies should strengthen the estimated causal structure. Thus, comparing the  $F$ -statistics for causality from the filtered and unfiltered models gives information on how important the excluded frequencies are in the baseline results.

## 1. THE BASELINE CAUSALITY RESULTS

Obtaining baseline results is relatively straightforward. The data used is monthly and covers the sample period 1959:1 to 1989:12, with appropriate allowances made for differencing and lags. The measure of aggregate activity used is industrial production. Money is measured as M1, the interest rate is the three-month T-bill rate, and the price level is the CPI. All data are from the *Citibase Data Bank*.

As in Stock and Watson (1989), unit roots are removed from the logs of money, output, and the price level and from the level of the interest rate. Thus, the basic model is

$$Z_t = f(t) + \sum_{j=1}^J A_j Z_{t-j} + u_t \quad (1)$$

where  $Z_t = [Y_t, M_t, P_t, R_t]^T$ ,  $Y_t$  is the growth rate of industrial production,  $M_t$  is money growth,  $P_t$  is the inflation rate, and  $R_t$  is the change in the nominal interest rate. Three separate models of the trend component  $f(t)$  are examined, no trend ( $f(t) = c_0$ ), a linear trend ( $f(t) = c_0 + c_1 t$ ), and a quadratic trend ( $f(t) = c_0 + c_1 t + c_2 t^2$ ). The  $A_j$  are coefficient matrices,  $u_t$  is the column vector of disturbances, and  $J$ , the lag length of the VAR, is 12.

Table 1 summarizes the baseline causality results. The table contains  $F$ -statistics

TABLE 1  
BASELINE CAUSALITY RESULTS

No Trend	Definitions of Trend $f(t)$ Linear Trend	Quadratic trend
2.47**	A. $\Delta \ln M_t \rightarrow P_t$ 2.45**	1.94**
4.21**	B. $\Delta \ln M_t \rightarrow \Delta R_t$ 4.17**	4.84**

\*\*Significant at the 5 percent level. There are 310 degrees of freedom for the model with no trend, 309 for the model with a linear trend, 308 for the model with a quadratic trend, and 12 restrictions. The  $F$ -statistic corresponding to a 5 percent significance level rounded to the nearest hundredth is the same in all three cases ( $F_{.05} = 1.78$ ).

for whether lags of innovations to money growth help to predict inflation and changes in interest rates.<sup>4</sup> As can be seen in Table 1, money growth significantly causes both inflation and changes in the nominal interest rate for all three trend specifications.

2. CAUSALITY RESULTS ACROSS SPECTRAL FREQUENCY BANDS

Which frequency movements in money growth, inflation, and changes in the interest rate lie behind the baseline results? The procedure used to answer this question is to transform the data to the frequency domain, zero out some of the frequencies, transform the data back to the time domain, perform new causality tests, and compare the new results to the baseline (unfiltered) results. Following Engle (1974, 1978), define the row vector  $w_k$  as

$$w_k = (1, e^{i\theta_k}, e^{2i\theta_k}, \dots, e^{(T-1)i\theta_k}) \tag{2}$$

where  $\theta_k = 2\pi k/T$ . Now, consider a particular element of the vector  $Z_t$ , say  $M_t$ . Let  $M = [M_0, M_1, \dots, M_{T-1}]^T$ . Then  $w_k M / \sqrt{T}$  is the  $k$ th element of the finite Fourier transform of  $M$ . Next, define  $\tilde{M} = WM$  where  $W = [w_0, w_1, \dots, w_{T-1}]^T$ .  $\tilde{M}$  is a  $T$  element vector with complex entries, each of which correspond to a different frequency. The objective is to exclude some of the frequencies from  $\tilde{M}$ . To accomplish this, construct a  $T \times T$  matrix  $S$ , where  $S$  has ones on the diagonal elements corresponding to included frequencies and is zero elsewhere, and obtain  $S\tilde{M}$ . Finally, define  $M^* = W^t S W M = W^t S \tilde{M}$  where  $t$  means the complex conjugate of the transpose. This is the inverse Fourier transform of  $S\tilde{M}$ .

The next step is to let  $Z_t^{M^*} = [Y_t, M_t^*, P_t, R_t]^T$ . Then write the new VAR model:

$$Z_t^{M^*} = \sum_{j=1}^J A_j Z_{t-j}^{M^*} + u_t \tag{3}$$

4. Following Stock and Watson,  $F$ -statistics rather than variance decompositions and impulse response functions are used to assess causality so that the results here can be compared directly to the results of earlier studies. The limitations inherent in the use of  $F$ -statistics in multivariate VAR models (that is, models with more than two variables) is acknowledged.

This is the VAR model with designated frequencies removed from one of the variables, in this case from  $M$ . This model is estimated and the  $F$ -statistics for causality are compared to the baseline results from model (1). If the excluded frequencies are responsible for the causality results, the  $F$ -statistics from model (3) should drop below the baseline results from model (1).

The approach to excluding frequencies used here is to successively and cumulatively remove particular frequencies from the data. Consider causality from money growth to inflation. First, two-month cycles are removed from the data on money growth, and a causality test is performed. Next, all frequencies less than or equal to three months are removed, and again a causality test is performed. Then, all cycles less than or equal to four months are removed from the data, and a causality test is performed. This procedure is continued until all cycles less than or equal to thirty months are removed from the data prior to performing the causality test. When the procedure is completed, there are twenty-nine test statistics corresponding to cumulatively removing cycles from two to thirty months from the data on money growth. The results are then plotted with the  $F$ -statistics for causality on the vertical axis, and the period of the cycle removed on the horizontal axis.<sup>5</sup> The effects of cumulatively removing cycles from money growth can then be assessed by comparing the  $F$ -statistics in the diagram to the baseline result.<sup>6</sup>

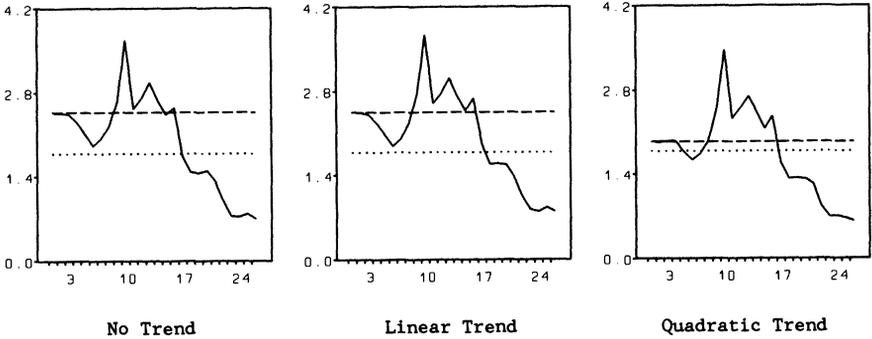
To ascertain which frequency movements in inflation are the most important in producing the baseline results, the causality tests are repeated with cycles from two to thirty months cumulatively removed from the data on inflation and the results are plotted as described in the previous paragraph. From the two diagrams, the frequencies in money growth and inflation that are responsible for the baseline money-inflation causality results are identified. A similar procedure is used for causality from money growth to the change in the interest rate. Cycles are removed from money growth and the change in the interest rate separately and the results are plotted relative to the baseline, unfiltered model.

Figure 1 presents the results for removing cycles from two to thirty months in duration from money growth and inflation. The effects of removing cycles from money growth are shown in the top row of Figure 1 for the three methods of trend removal discussed earlier, no trend, a linear trend, and a quadratic trend. The results are very similar across the three cases. The  $F$ -statistics initially decline below baseline as cycles six months or less in duration are removed from money growth. Then there is a large increase in the  $F$ -statistics back to and above baseline as cycles from seven to ten months are excluded. This is followed by a gradual decline as cycles

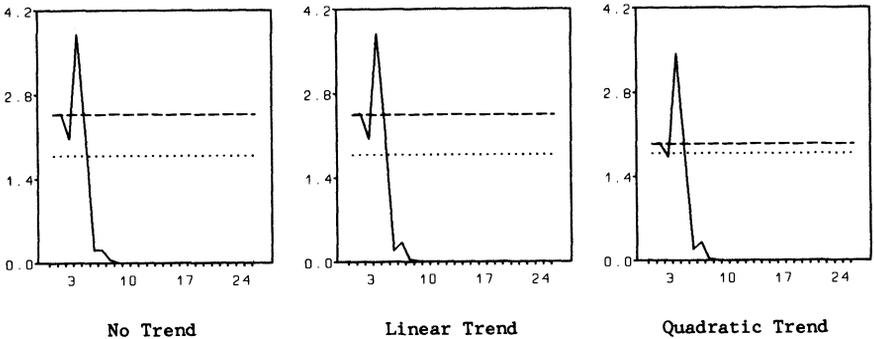
5. In the graphs, the horizontal axis, which measures the cumulative cycles removed, ranges from 1 to 30. The test statistic corresponding to one month at entry one, which is below the Nyquist frequency, is defined as the baseline statistic. The 5 percent significance level is also shown in the diagrams.

6. It should be noted that there is a compression of the cyclical frequencies as you move from higher to lower frequencies along the horizontal axis of the spectrum. That is, the distance between two- and three-month periods on the spectrum is larger than the difference between three- and four-month periods, which is larger than the distance between four- and five-month periods, etc. In the figures presented here, the months are spaced equally along the horizontal axis.

Cycles Filtered from Money Growth



Cycles Filtered from Inflation



----- Horizontal line showing the baseline F-Statistic.  
 ..... Horizontal line showing the 5% Significance Level ( $F_{.05}$ ).

The horizontal axis measures the cumulative monthly period of the filtered cycles, and the vertical axis is the corresponding F-statistic.

FIG. 1. Causality from Money Growth to Inflation for the Model  $Y-M1-P-R$

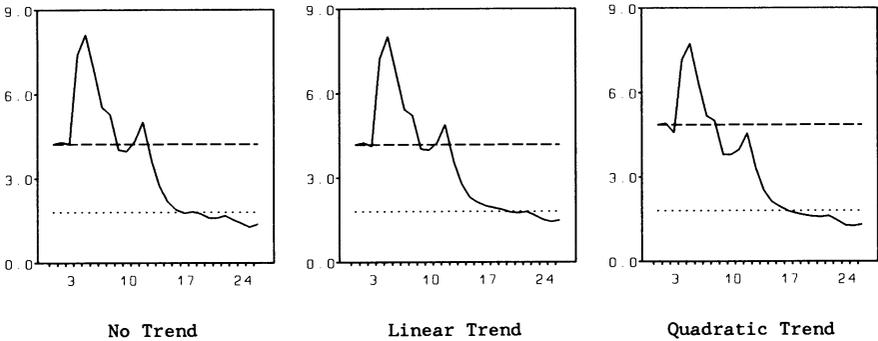
from eleven to twenty-four months are removed, and a leveling off from twenty-five to thirty months. These results indicate that money-inflation causality is due primarily to cycles in money from eleven to twenty-four months in duration, although there is some contribution from cycles two to six months long.

The results for the removal of cycles from inflation for the three trend specifications are shown in the bottom row of Figure 1. The  $F$ -statistics decline slightly below baseline when three-month cycles are removed, increase back to and above

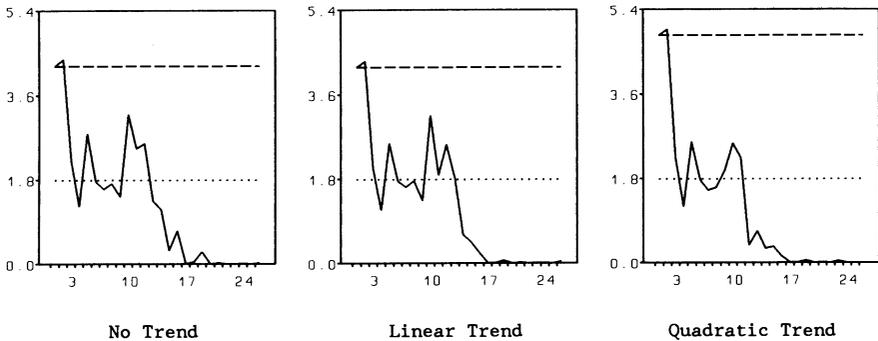
baseline for the removal of four-month cycles, and then decline rapidly when cycles of five to six months are removed. Thus, money growth appears to cause three-month cycles in inflation, which explain a small part of the baseline results, and cycles from five to six months, which are the main contributor to the baseline results.

Figure 2 shows the results for money-interest rate causality. In the top row, which shows the effects of filtering cycles from money growth, the *F*-statistics increase

Cycles Filtered from Money Growth



Cycles Filtered from Changes in the Nominal Interest Rate



----- Horizontal line showing the baseline *F*-Statistic.  
 ..... Horizontal line showing the 5% Significance Level ( $F_{.05}$ ).

The horizontal axis measures the cumulative monthly period of the filtered cycles, and the vertical axis is the corresponding *F*-Statistic.

FIG. 2. Causality from Money Growth to Changes in the Nominal Interest Rate for the Model *Y-M1-P-R*

substantially above baseline when four- and five-month cycles are removed, indicating that these frequency movements in money growth are noise which obscures the causal relationship. The  $F$ -statistics decline rapidly from six to sixteen months, decline slightly from seventeen to twenty-five months, and then turn back up slightly from twenty-six to thirty months. The main contribution to the baseline results is the six- to sixteen-month range for money growth.

In the bottom row, where cycles are filtered from the change in the interest rate, the  $F$ -statistics decline rapidly for the removal of three- and four-month cycles, level off or increase from five to ten months, and then decline rapidly from eleven to fourteen months. Thus, money causes three- to four-month and eleven- to fourteen-month cycles in the change in the interest rate.<sup>7</sup> It is interesting that these frequencies correspond closely to the timing of the liquidity effect and the anticipated inflation effect identified in previous research (see Friedman 1968, Stokes 1983, and Christiano 1991).

In Figures 3 and 4, the analysis is repeated with output omitted from the VAR model. In the figures, the solid lines show the new results for the VAR model with output omitted and the broken lines show the corresponding results from Figures 1 and 2 where output is included. Figure 3 and 4 show that omitting output from the VAR model has very little impact on the results. Figures 5 and 6 provide a further check on the robustness of the results. These figures show the results for money measured as M2 rather than M1. The solid lines in the figures are the results using M2 while the broken lines show the comparative results from Figures 1 and 2 where M1 is the measure of money. The figures show that the results are not changed substantially when M2 rather than M1 is used in the analysis.

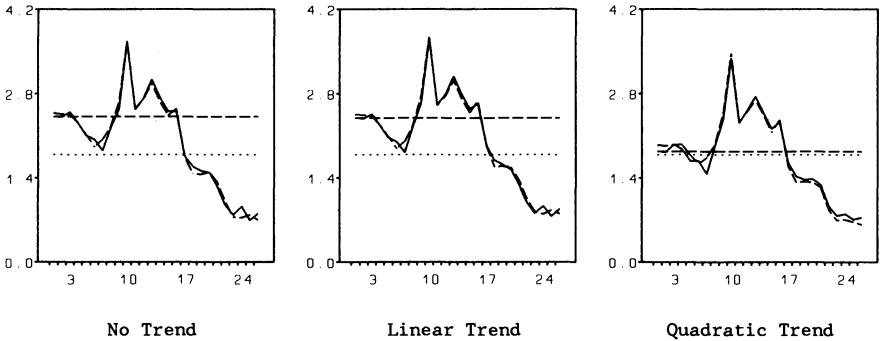
Summarizing, money growth-inflation causality is mainly due to cycles from eleven to twenty-four months in money causing five- to six-month cycles in inflation. Money growth-interest rate causality is due to six- to sixteen-month cycles in money growth causing three- to four-month and eleven- to fourteen-month cycles in the change in the interest rate. These results are robust to dropping output from the empirical model and to measuring money as M2.

### 3. CONCLUSIONS

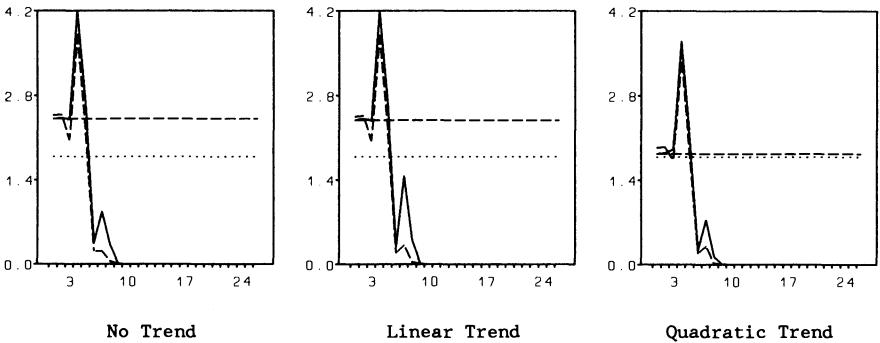
Using band spectral regression techniques, this paper shows that cycles in the money growth rate from one to two years long produce higher frequency cycles in inflation and the change in the nominal interest rate, and that there are two distinct

7. In this case, the results vary slightly across the three trend specifications. In all three trend specifications, there is a sharp decline when three- and four-month cycles are removed. In the model with no trend, there is also a steep decline from eleven to fifteen months and a more gradual decline from sixteen to seventeen months. With a linear trend, the steepest decline is from eleven to fourteen months with a more gradual decline from fifteen to seventeen months. In the case with a quadratic trend, the steepest decline is from eleven to twelve months, with a more gradual decline from fourteen to seventeen months. Overall, the steepest decline appears to be in the eleven- to fourteen-month range.

Cycles Filtered from Money Growth



Cycles Filtered from Inflation



----- Horizontal line showing the baseline F-Statistic.  
 ..... Horizontal line showing the 5% Significance Level ( $F_{.05}$ ).

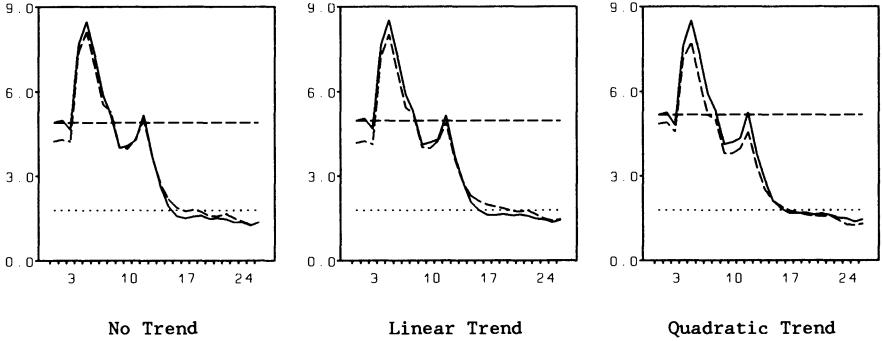
The horizontal axis measures the cumulative monthly period of the filtered cycles, and the vertical axis is the corresponding F-statistic.

FIG. 3. Causality from Money Growth to Inflation for the Model *M1-P-R*

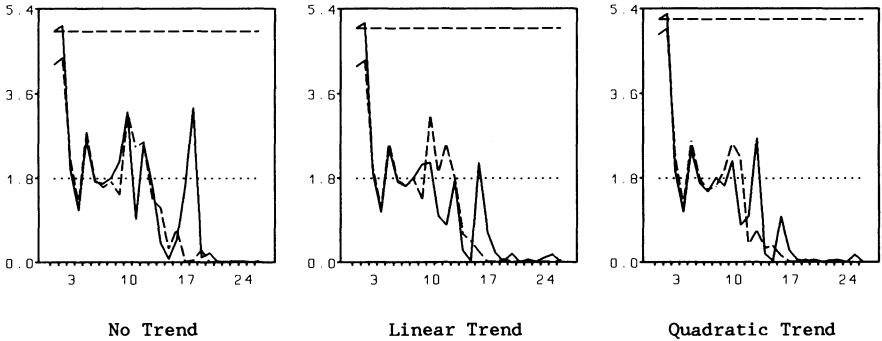
sets of cycles in the change in the nominal interest rate that correspond to the liquidity and anticipated inflation effects.

These results are important for understanding the dynamic relationship between money growth, inflation, and the nominal interest rate. Knowledge of the actual timing of the reduced-form responses of output, inflation, and interest rates to shocks in a variable such as money growth is essential in assessing which theoretical structures are consistent with the empirical evidence regarding reduced-form rela-

Cycles Filtered from Money Growth



Cycles Filtered from Changes in the Nominal Interest Rate



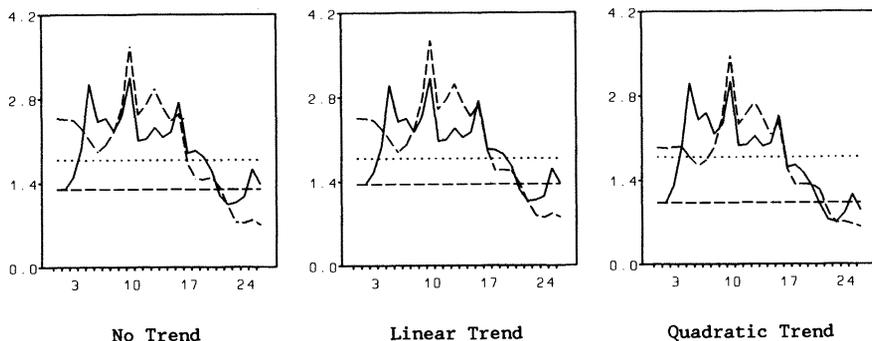
----- Horizontal line showing the baseline F-Statistic.  
 ..... Horizontal line showing the 5% Significance Level ( $F_{.05}$ ).

The horizontal axis measures the cumulative monthly period of the filtered cycles, and the vertical axis is the corresponding F-statistic.

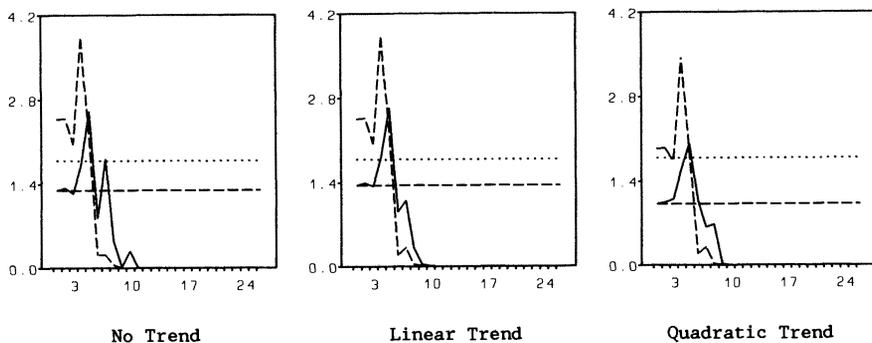
FIG. 4. Causality from Money Growth to Changes in the Nominal Interest Rate for the Model *M1-P-R*

tionships. The results imply that models generating a liquidity effect and an anticipated inflation effect are consistent with the data. It is well known that a variety of Keynesian and New Keynesian models are capable of producing liquidity and anticipated inflation effects. However, the frequency movements in money growth generating these effects must be one of two years long, movements of sufficient duration to be predictable. Incorporating this result into these models is a more challenging task.

Cycles Filtered from Money Growth



Cycles Filtered from Inflation



----- Horizontal line showing the baseline F-Statistic.  
 ..... Horizontal line showing the 5% Significance Level ( $F_{.05}$ ).

The horizontal axis measures the cumulative monthly period of the filtered cycles, and the vertical axis is the corresponding F-statistic.

FIG. 5. Causality from Money Growth to Inflation for the Model  $Y-M2-P-R$

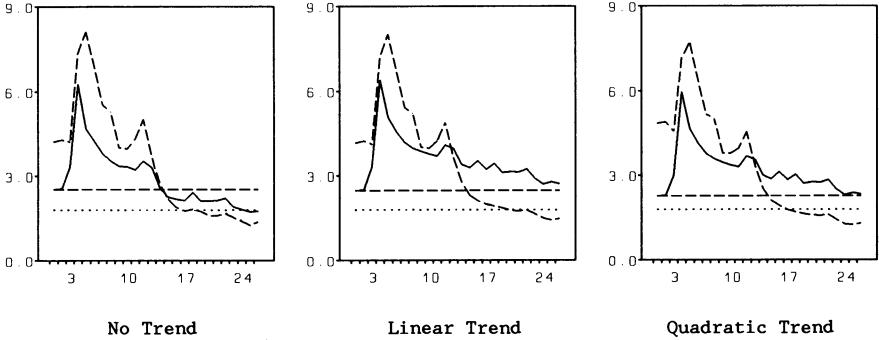
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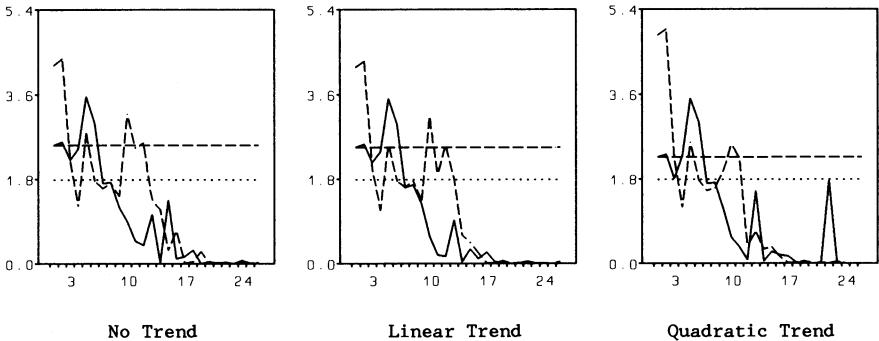
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Cycles Filtered from Money Growth



Cycles Filtered from Changes in the Nominal Interest Rate



----- Horizontal line showing the baseline F-Statistic.  
 ..... Horizontal line showing the 5% Significance Level ( $F_{.05}$ ).

The horizontal axis measures the cumulative monthly period of the filtered cycles, and the vertical axis is the corresponding F-statistic.

FIG. 6. Causality from Money Growth to Changes in the Nominal Interest Rate for the Model  $Y-M2-P-R$

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### [Footnotes]

<sup>1</sup> **The Role of Monetary Policy**

Milton Friedman

*The American Economic Review*, Vol. 58, No. 1. (Mar., 1968), pp. 1-17.

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