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MEASURING VARIABILITY OF MONETARY POLICY LAGS: A FREQUENCY DOMAIN APPROACH

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1. INTRODUCTION

The issue of monetary policy lags came to the fore in the classic Friedman-Culbertson debate of the 1960s (Friedman (1961), Culbertson (1960,1961)). Since then, an extensive literature has emerged around the issue , which has been critically surveyed by Rosenbaum (1985) and Purvis(1990).

The lags in the impact of monetary policy changes (proxied alternately by monetary base, money supply or short term interest rate) have been studied in relation to real output as well as prices; yet, the transmission mechanism underlying the triangular relationship has been but imperfectly understood. There is also much semantic confusion about definition of lags and disagreements about measuring their magnitude and variability. This is singularly unfortunate, since all these issues have important bearings on the conduct of monetary policy. We begin by offering brief comments on each of these issues.

The lag terminology has been variously understood in the literature. There is first of all the distinction between the *inside* and *outside lag*, the former reflecting the time elapsed between recognition that a monetary policy change is required, and the actual implementation of this change, whereas the latter refers to the span of time over which monetary policy actions affect the economy. Strictly speaking, it is only the *outside lag* which can be estimated by formal statistical methods and this is the sense in which the term lag will be understood throughout the paper. But even here, the term can have three distinct connotations:

(i) *impact lag :* the time elapsed between the introduction of a monetary policy change and its initial impact on the economy.

(ii) *peak lag:* the time required for a monetary policy impulse to attain its maximum effect and

(iii) *cumulative lag:* the time elapsed before the impulse is dissipated completely.

This, by no means, exhausts all the possible senses in which the term lag has been used in the literature.[1]

Approaches to the issue of measurement of the lag (and its variability) might be viewed as following into four categories. The earliest, possibly, was the one based on *reference-cycle turning point analysis* (Friedman (1961), Warburton (1971), Poole (1975) etc.). Another very popular method of analysis has been the reduced-form approach, usually focussing on a single-equation, but differing considerably in methodological details, ranging from simple regresssions (Anderson & Jordan (1968), Anderson & Karnosky (1972) etc.) to distributed lag models (Tanner (1979)), to the

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[1] Friedman (1961), for example, maintains that "when we refer to the lag, we mean something like the weighted average interval between action and its effects". Tanner (1979) develops a distributed lag model of nominal magnitudes regressed on money supply changes, in which the lag length is fixed but the coefficients are time varying, which is similar in spirit to the Cargill & Meyer (1972) approach .Both these approaches amount to measuring the varying impact magnitudes rather than varying lags *per se.*

spectral regressions of Cargill & Meyer (1972). The lag problem has also been analysed in the context of full-scale structural models via policy simulations (Kaufman & Laurent (1970), Fromm & Klein (1975) etc.). Finally, a few investigations have proceeded via non-parametric methods (most notably Uselton (1974) and Perryman (1980)).

The time-varying spectrum approach that we have adopted in this paper, is essentially a non-parametric approach, but one which does not seem to have been previously applied in this context. In traditional spectral analysis, a specific lag (between two series) is derived from the so-called phase function, at cycles corresponding to various frequencies (Fishman (1969)). This lag may vary over the different frequencies *but for a fixed frequency is constant over time.* The time-varying spectral approach allows for the further possibility of *the lag varying for any fixed frequency over time.* The exact interpretation of the lag is postponed to a later section.

The plan of our paper is as follows. The next section supplies the theoretical context to our exercise. Section 3 outlines the essential features of the evolutionary spectrum and related concepts, whereas Section 4 deals with the concept of group delay and its estimation. The empirical results and their interpretation form the subject matter of Section 5, whereas further non-parametric results are reported in Section 6. Conclusions are gathered in Section 7.

2.THEORETICAL CONSIDERATIONS

The magnitude of the lag is intimately related to the transmission channels of monetary policy. It is now customary to distinguish four transmission channels (Mishkin (1995), Bernanke & Gertler (1995) and Taylor (2000)).

(i) the credit channel

(ii) the interest rate channel

(iii) the exchange rate channel

(iv) the asset prices channel

These channels may operate in isolation or more likely, together. Some of them , such as the asset prices channel, take a long time to work out, others such as the exchange rate channel, may be faster. The actual lag will thus be a reflection of which transmission channels are the predominant ones. Friedman inclined towards long lags, possibly because he focussed exclusively on the asset prices channel- a view seriously disputed by Kareken and Solow (1963), Mayer (1967), Tanner (1979) etc.

The rational expectations literature and the assumption of market efficiency, constitute the core of the *new classical macroeconomics*, which commands considerable allegiance in the profession currently. In conjunction with the celebrated Lucas Critique (1976), new classical macroeconomics, implies that systematic monetary policy would not only be ineffective, but the responses would depend unpredictably on the specific policy regime adopted. The study of lags then becomes rather pointless.

An additional complication comes from the paper by Bryan and Gavin (1994), who building up on some earlier results of Tucker (1966), Sargent (1976) etc, show that in a rational expectations model with flexible prices, any *hysteresis* in money supply growth will result in long and variable observed lags in monetary policy, even though the actual transmission mechanism structural lags may be quite short. However this "money illusion" is a direct function of the persistence in money supply growth, and tends to disappear once the persistence is reduced.

Several factors have contributed to a revival of interest in monetary policy lags in recent years. Earlier critics of rational expectations had focussed on various kinds of market imperfections (price inflexibilities, staggered labour contracts, inventory strategies etc.) which could interfere with the neutrality of money in rational expectations models. More recently, forward-looking monetary policy rules (Batini & Haldane (1999)), asset price volatility (Bernanke & Gertler (2000), Cecchetti et al (2000)), political business cycles (Cukierman et al (1992)), financial innovations (Gabb & Mullineux (1995)) and *menu costs* under monopolistic competition (Mankiw(1985)) have been some of the factors emphasised, as likely to introduce non-neutrality features in rational-expectations models and thereby permit elbow-room for systematic monetary policy to influence real output.
The issue of monetary policy lags is also tied up with the entire gamut of issues raised by the recently resurrected *New Keynesian Phillips curve* (Roberts (1995), McCallum (1997) etc.), which may be viewed as a dynamic extension of the static new Keynesian models of price adjustment proposed in Akerlof & Yellen (1985), Blanchard & Kiyotaki (1987) and others. Ball (1994) has demonstrated how the *New Keynesian Phillips curve* implies that a credible disinflationary policy by the central bank should result in an increase in output, before it leads to a rise in inflation. A failure to observe this outcome, could be attributed either to the disinflation not being perfectly credible, or to inflation hysteresis, or to the breakdown of the Phillips curve itself. Further discussion of these issues is available in Clarida et al. (1999) and Mankiw (2000), who also comment briefly on how these issues are

related to monetary policy lags. The gist of their arguments, we believe, can be captured in the following empirically testable proposition.

Proposition: *A short-run New Keynesian Phillips curve type of trade-off can be detected if the money supply shocks (associated with unanticipated monetary policy changes) either lead both output and inflation or lag both, and further the lead/lag in respect of inflation is longer than that in respect of output (see e.g. Mankiw (2000) p.16-21)*

Our time-varying spectral methodology has the specific advantage of enabling the testing for the existence of this trade-off at any given point of time (i.e. trace a dynamic short-run Phillips curve). Further, by choosing appropriate frequencies, we can test the hypothesis over differing definitions of the short-run.

There, thus, seem to be two major interlinked issues in the monetary lag problem. Firstly, the issue of setting up an appropriate econometric methodology to record the lags which may be changing, possibly, in every time period . Secondly, to examine whether these changes in lags are purely random or could be explained in terms of certain systematic variables. Several studies (e.g. Vernon (1977), Tanner (1979), Bordo & Choudhri (1982), Bryan & Gavin (1994)) have sugested, for example, that lags can vary with (i) shifts in the demand for money function associated with financial deregulation, (ii) global integration of capital markets (iii) international currency substitution (iv) non-linear dependence of money demand on interest rates, etc. However, without satisfactory resolution of the first issue, not much credence can be attached to the latter group of results. Our paper, therefore, focusses on the first issue and obtains estimates for monetary policy lags varying over time. This is done by a combination of three fundamental concepts in modern spectral analysis :

(i) the evolutionary spectrum and cross-spectrum (Priestley (1965,1988))

(ii) the "group or envelope delay" due to Hannan and Thomson (1971) and

(iii) Non-parametric density function estimation (Priestley and Chao (1972))

The methodology is applied to study monetary policy in India over the twenty –three year period April 1977 to March 2000 using monthly data.

The observed time-varying lags can be sought to be explained in terms of some of the variables discussed above, though this has not been attempted in this paper, primarily because of lack of data availability (in the Indian context) on such critical variables as currency substitution, suitable indices of financial liberalisation or global integration.

3.EVOLUTIONARY SPECTRUM, CROSS-SPECTRUM AND RELATED CONCEPTS

Traditional spectral analysis is confined to stationary and purely indetermininistic processes (e.g. Fishman (1969)). However several series occurring in economics are non-stationary to begin with. The standard approach is, then, to apply a filtering device to render the series stationary. Filtering however has two undesirable consequences: (i) it may eliminate information on several frequencies of interest and (ii) it may introduce artificial distortions of the spectrum.

The literature on time-varying spectra attempts to generalise the concepts of the spectrum (and cross-spectrum) to series which need not be necessarily covariance stationary. Of course, not every type of non-stationarity can be satisfactorily accommodated, yet the class of non-stationary processes to which the methods can apply is sufficiently wide to be of general practical interest. A number of alternative approaches have been proposed in the literature (e.g. Page (1952), Tjostheim (1976), Melard (1985), and Priestley (1965, 1988)). Of these, the evolutionary spectrum of Priestley (1988) is particularly appealing, both because it has a recognisable physical interpretation and because it encompasses several other approaches as special cases. The basic concepts and the theoretical results are located in Priestley (1988). Here we confine ourselves to the features pertinent to estimation.

The evolutionary spectrum may be estimated using Priestley's "double window" technique.

Suppose (T+1) observations X(0), X(1)…. X(T) are given on a discrete time series X(t) whose evolutionary spectrum is to be obtained. We assume that X(t) is *oscillatory* (Priestley (1988))

For any given frequency λ_o , the data are first passed through a linear filter centred at λ_o , yielding an output $U_t(\lambda_0)$, where $\{g_p\}$ are suitably chosen weights.

$$U_t(l_0) = \sum_{p=t-T}^{t} g_p X(t-p) \exp\{-i l_0 (t-p)\} \qquad (1)$$

Thus $U_t(\lambda_0)$ is essentially a weighted average of the contribution to X(t) from components with frequency λ_0 , the weights declining exponentially away from X(t). A first-stage approximation to the local power spectral density at t from components at frequency λ_0 is given by $|U_t(\lambda_0)|^2$. This is double-smoothed to give an improved estimate of the power spectrum, which we denote by $h_t(\lambda_0)$. Thus, for any t and λ, we may define

$$\hat{h}_t(l) = \sum_{q=t-T}^{t} w_q \left| U_{t-q}(l) \right|^2 \qquad (2)$$

with { w_q } being suitably chosen weights.

The evolutionary spectrum estimate thus depends on the choice of the windows {g_p } and {w_q }. The following "double window" due to Priestley (1988) is found to be particularly useful in applications.

$$(i)\ g_p = \frac{1}{2\sqrt{hp}} \qquad |p| \leq h$$
$$g_p = 0 \qquad |p| \succ h$$
$$(ii)\ w_q = \frac{1}{T'} \qquad |q| \leq \frac{T'}{2}$$
$$w_q = 0 \qquad |q| \succ \frac{T'}{2}$$

The "double window" is thus completely specified by the choice of h and T' On the basis of extensive Monte Carlo evidence, Chan and Tong (1975) suggest the following values for these parameters

(i) h=7 (ii) T/6 ≤T'≤ T/4

Further Monte Carlo evidence is reported in Nachane (1997).

The above ideas can be generalised without too much difficulty to the bivariate case (see Priestley and Tong (1973)). Consider, for example, a discrete parameter bivariate process {X(t), Y(t)}, in which each component is an "oscillatory" process. Their evolutionary cross-spectrum $h_{t,xy}$ is defined analogously to that of the cross-spectrum in the stationary case, viz. as the mean of the product of the amplitudes of the corresponding frequency components in the two processes, except that the amplitudes are time-dependent, so that the evolutionary cross-spectrum is time dependent too.

Since the evolutionary cross-spectrum is a complex quantity, we may write it as

$$h_{t,xy}(l) = c_{t,xy}(l) - iq_{t,xy}(l) \qquad (3)$$

The real quantities $c_{t,xy}(\lambda)$ and $q_{t,xy}(\lambda)$ may be referred to (by analogy with the stationary case), as the evolutionary co-spectrum and the evolutionary quadrature spectrum respectively.

Introducing the notation $h_{t,xx}(\lambda)$ and $h_{t,yy}(\lambda)$ for the respective evolutionary spectra of X(t) and Y(t) , we may obtain the following further definitions.

Def. 1: The coherency spectrum between X(t) and Y(t) may be defined as

$$W_{xy}(l) = \left|h_{t,xy}(l)\right| \left\{h_{t,xx}(l)\, h_{t,yy}(l)\right\}^{-\frac{1}{2}} \qquad (4)$$

and may be interpreted as the modulus of the correlation coefficient between the two series at frequency λ .

Def. 2: The evolutionary gain-spectrum and the evolutionary phase spectrum may be defined as respectively

$$G_t(l) = \frac{\left[c^2_{t,xy}(l) + q^2_{t,xy}(l)\right]^{\frac{1}{2}}}{\hat{h}_{t,xx}(l)} \qquad (5)$$

$$f_t(l) = \tan^{-1}\left\{\frac{q_{t,xy}(l)}{c_{t,xy}(l)}\right\} \qquad (6)$$

The quantities (5) and (6) have interpretations similar to that in the stationary case.

The estimation of the evolutionary cross-spectrum proceeds once again on the basis of a "double window" technique. Let (T+1) observations [{X(0), Y(0)}, {X(1), Y(1)},… {X(T), Y(T)}] be available on the bivariate series {X(t), Y(t)}. Then, for a suitable window $\{g_p\}$ we define the two filters

$$U_t(l_0) = \sum_{p=t-T}^{t} g_p X(t-p)\exp(-i l_0 (t-p)) \qquad (7)$$

and

$$V_t(l_0) = \sum_{p=t-T}^{t} g_p Y(t-p)\exp(-i l_0 (t-p)) \qquad (8)$$

The evolutionary cross-spectrum estimate is now defined as

$$\hat{h}_{t,xy}(l) = \sum_{q=t-T}^{t} w_q U_{t-q}(l) V^{*}_{t-q}(l) \qquad (9)$$

with the superscript * denoting complex conjugates and $\{w_q\}$ are suitably chosen weights.

Once the cross- spectrum has been estimated, the quantities (4) - (6) can be estimated by replacing the various terms involving $h_{t,xy}$, $h_{t,xx}$ etc. by their estimates. Tong (1972) and Priestley and Tong (1973) have derived sampling properties of the coherency spectrum, the evolutionary gain spectrum and the evolutionary phase spectrum. These calculations are rather involved and the only results we report, pertain to the phase spectra, which have a direct bearing on our problem.

The sampling properties of the phase spectra are, of course, dependent on the choice of the window, and the following derivations are predicated on the *double window* discussed above, which we now write somewhat differently as:

$$(i) g(u) = \left(\frac{1}{2\sqrt{hp}}\right), \quad [|u| \le h]$$
$$g(u) = 0, \qquad otherwise$$

$$(ii)\, w_{T'}(t) = \left(\frac{1}{T'}\right), \quad [|t| \le \left(\frac{T'}{2}\right)]$$
$$w_{T'}(t) = 0, \qquad otherwise$$

Tong (1972) defines the following three quantities

$$\Gamma(w) = \int_{-p}^{p} g(u) \exp(iuw) du \qquad (10)$$

$$B_{T'}(l) = \int_{-p}^{p} \exp(-i l t) w_{T'}(t) dt \qquad (11)$$

$$C = \lim_{T' \to \infty} \{T' \int_{-p}^{p} \left| B_{T'}(l) \right|^2 dl\} \qquad (12)$$

The evaluation of the above quantities can proceed via standard complex residue techniques (see e.g. Sveshnikov & Tikhonov (1971)) and for our choice of the *double window* yield

$$B_{T'} = (2/T')\sin(lT'/2) \qquad (13)$$

$$\Gamma(w) = \{\sin(hw)\}/(hp) \qquad (14)$$

$$C = \frac{8p}{(T')^2} \qquad (15)$$

The asymptotic variance of the evolutionary phase spectrum is given by

$$Var[f_t(l)] = (C/2T')\{\int_{-p}^{p} \left| \Gamma(q) \right|^4 dq\} \frac{[1 - W_{xy}^2]}{W_{xy}^2}$$

…(16)

(where $W_{xy}(\lambda)$ is the coherency spectrum defined by (4))

The integral in (16) evaluates to

$$\int_{-p}^{p} \left| \Gamma(q) \right|^4 dq = (1/ph^2)\{0.5 + (4/h)\} \qquad (17)$$

(16) and (17), together with the unbiasedness of the evolutionary phase spectral estimator and its asymptotic normality, permit the computation of asymptotic confidence intervals for $\varphi_t(\lambda)$ for any value of t or λ.

4. GROUP DELAY AND ITS ESTIMATION

The evolutionary phase spectrum described in (6), faces severe problems of interpretation. In the stationary case, the quantity $[\phi(\lambda)/\lambda]$ has often been used as an approximate measure of the time delay between the two series at frequency λ (see Fishman (1969) Granger and Hatanka (1964) etc). But the interpretation is ambiguous, since the phase is indeterminate upto a multiple of 2π. Even the convention of restricting $\phi(\lambda)$ to the range $(-\pi,\pi)$ does not overcome the ambiguity (see Priestley (1981)).

The concept of "group delay" introduced by Hannan and Thomson (1971) for the case of jointly stationary series has a direct interpretation in terms of the lead or the lag of one series relative to another.

Def 3: Let X(t) and Y(t) be two jointly covariance stationary series and let $h_{xy}(\lambda) = c_{xy}(\lambda) - iq_{xy}(\lambda)$, be their cross spectrum. Further, defining the phase as

$$f_{xy}(l) = \tan^{-1}\left\{\frac{q_{xy}(l)}{c_{xy}(l)}\right\} \qquad (18)$$

the group delay $\delta(\lambda)$ can be written as

$$d(l) = -\left[\frac{df(l)}{dl}\right] \qquad (19)$$

Empirical estimation of the group delay is handicapped by the fact that (19) requires for its computation a continuous record of $\phi(\lambda)$ as a function of λ , whereas in practical situations, we will only observe $\phi(\lambda)$ at a finite set of frequencies $\lambda_1 \dots \lambda_m$. The problem is analogous to the density function estimation issue on which a huge literature already exists. However, in the spectral context, some special considerations apply. We follow the method, originally suggested by Tischendorf and Chao (1970). The method may be briefly described as follows.

Suppose (for a given pair of series X(t) and Y(t)) the phase $\phi_{xy}(\lambda)$ has been computed at m equispaced frequencies $\lambda_1 \dots \lambda_m$ (we assume that each λ_i has been divided by 2π, so that $0 \le \lambda_i \le 1$)

Let $\lambda_{j+1}-\lambda_j = \eta$, $j = 1\dots(m-1)$

Also, let $y_j^0 = \phi(\lambda_j)$, the observed phase value at frequency λ_j

Priestley and Chao (1972) suggest the following estimator of $\varphi(\lambda)$

$$f(l) = h \sum_{i=1}^{m} y_i^0 W_k(l - l_i) \qquad (20)$$

where k is a "bandwidth parameter" and

$$W_k(x) = \left(\frac{1}{k}\right) W_0\left(\frac{x}{k}\right) \qquad (21)$$

where $W_0(x)$ is a general type of smoothing function satisfying

(i) $W_0(x) \geq 0 \quad \forall x$

(ii) $\int_{-\infty}^{\infty} W_0(x)\,dx = 1$ and

(iii) $\int_{-\infty}^{\infty} [W_0(x)]\,dx \prec \infty$

Several smoothing functions have been suggested in the literature of which the two most popular have been:

(a) the Quadratic weight function defined as

$$\begin{aligned} W_0(x) &= 0.75(1 - x^2), & |x| \leq 1 \qquad (22) \\ W_0(x) &= 0 & \textit{otherwise} \end{aligned}$$

and

(b) the Gaussian weight function

$$W_0(x) = \frac{1}{\sqrt{2p}} \exp(-0.5x^2) \qquad (23)$$

With either choice of the weight function, (21) will be a consistent estimate of the true phase function φ(λ) provided the bandwidth parameter k satisfies the following:

$$k \to 0 \;\; as \;\; m \to \infty \;\; and\, h \to 0, \;\; in\, such\, a\, way\, that$$
$$(\frac{h}{k}) \to 0 \;\; i.e. \; h = O(k) \qquad (24)$$

The condition (24) can be ensured by choosing

$$k = m^{-a}, \quad a \prec 1 \qquad (25)$$

The group delay can now be routinely obtained as

$$\hat{d}(l) = -\frac{d\hat{f}(l)}{dl} \qquad (26)$$

where $\hat{f}(l)$ *is given by* (20), $W_0(x)$ *by either* (22) *or* (23) *and* k *is chosen to satisfy* (25)

The concept of group delay can be generalised in a straightforward fashion to the non-stationary case. The time -varying group delay may be defined as

$$d_t(l) = -\frac{df_t(l)}{dl} \qquad (27)$$

where the evolutionary phase $\phi_t(\lambda)$ is defined by (6).

The preceding ideas can be applied to the estimation of (27), bearing in mind that the quantity $\hat{f}(l)$ of (20), will have to be estimated separately for each t. Thus (20) is slightly modified to

$$\hat{f}_t(l) = h \sum_{i=1}^{m} \hat{j}_t(l_i) W_k(l - l_i) \qquad (28)$$

The computations increase in number but no new principles are called into play. Further the group delay is either

$$\hat{d}_t^{(1)}(l) = (1.5)\, h\, k^{-3} \sum_{i=1}^{m} \hat{f}_t(l_i)(l - l_i) \qquad (29)$$

or

$$\hat{d}_t^{(2)}(l) = (h / k^{-3}\sqrt{2p}) \sum_{i=1}^{m} \hat{f}_t(l_i)(l - l_i) \exp\{-0.5k^{-2}(l - l_i)^2\}$$

…(30)

depending on whether the chosen weight function is quadratic or Gaussian. Confidence intervals for (29) and (30) can be routinely computed from those for $\hat{j}_t(l)$.

5.EMPIRICAL RESULTS

A. Data Considerations

In assessing the impact of monetary policy, the first decision pertains to the choice of an appropriate variable for measuring the monetary policy stance-this is usually either a money supply variable or a short term interest rate. Interest rate deregulation is a very recent phenomenon in India and even in today's liberalised financial set up, the interest rate is far from being used as an operational target. Hence we select the money supply as the variable to proxy the impact of monetary policy. Since the lags involved may often be less than a year, an annual model has severe limitations. We therefore resort to a monthly model, which also yields substantial high-frequency data suitable to the techniques that we propose to apply. However, the decision to work with monthly data brings in its wake, its own set of problems. Because data on Indian GDP is unavailable except on an annual (or semi-annual) basis, we have to proxy the output variable by the IIP (Index of Industrial Production), on which monthly data is available in the Indian context. This is a significant limitation, increasingly so in recent years, when services are becoming predominant in national output. Nevertheless, there is no reason to believe that the impact of money on the non-industrial sector is likely to differ substantially from the impact on the industrial sector. Thus, at least, as a first approximation, our analysis is not devoid of meaningful interpretations.

The period of our analysis is April 1977- March 2000 and the following combinations of bivariate series were studied.

(i) g and m1

(ii) g and m3

(iii) p and m1

(iv) p and m3

(Here, g is the rate of growth of IIP (index of industrial production), p the inflation based on the WPI (wholesale price index), m1 the rate of growth of M1 (narrow money) and m3 the rate of growth of M3 (broad money). All rates of growth are on an annualized basis)

The first two cases thus, pertain to the impact of narrow and broad money on the real output growth and the next two cases analyse the impact of narrow and broad money on inflation.

The main sources of data are the following :

IIP, WPI	RBI *Report on Currency and Finance*
M1, M3	RBI *Working Group on Money Supply Report (1998)* & issues of the *RBI Bulletin*

<u>B. VAR Model</u>

The starting point of our analysis is a trivariate VAR relating our three variables (money supply growth rate as proxied by either m1 or m3, output growth rate g and inflation p) of interest. We thus have the following two VARs ordered as

(i) $m1 \rightarrow g \rightarrow p$

(ii) $m3 \rightarrow g \rightarrow p$

Both VARs are identified by the standard Choleski decomposition, since we are reluctant to impose too much a priori structure on the model.

Prior to the estimation of the VARs, we checked each of m1, m3, g and p for unit roots and seasonal unit roots via the HEGY (Hylleberg et al (1990)) framework, as suitably extended to the monthly context by Beaulieu and

Miron (1993). The details of the tests, as well as the estimated VARs, are not reported here[2] in the interests of brevity. A major simplification with our analysis is that all our variables are free of unit roots as well as seasonal unit roots. We allow however, for deterministic seasonality by using seasonal dummies in the estimated VARs.

The residuals from the VARs are identified as shocks to the respective variables, and our subsequent analysis is occupied with the lags between the shocks to money supply (m1 or m3) and the associated shocks to g and p.

C. Evolutionary Spectral Estimation

The three concepts of relevance to the understanding of the bivariate relationships of our interest, are (i) the coherency (ii) the evolutionary gain spectrum and (iii) the (evolutionary) group delay. The interpretation of these quantities has already been noted in Section 2. Our computations will yield in all (276×120) entries for each entity[3]. Obviously, such a mass of information can only be confusing. And we, therefore, record the entities only for a selection of time periods and frequencies. We decided to select two representative months each year viz. April and November, which have usually coincided with the monetary policy announcements in India for the slack and busy seasons respectively.

Our chosen values for t thus run from April 1977 to October 1999 at 6-monthly intervals i.e. t = 1, 7, 13,…259, 265, 271.

It was also decided to select three representative frequencies, corresponding to the short, medium and long runs. It is, of course, well known that low

[2] Results available on request from authors.

[3] Each of these entities varies over time (276 months) as well as frequencies (a total of 120)

coherencies make phase estimates unreliable (Granger & Hatanaka (1964)), and hence in the choice of the representative frequencies, this consideration must also be borne in mind. Fortunately, as demonstrated by Priestley (1988), the evolutionary coherency is independent of time, and this somewhat simplifies our task. For all our bivariate series combinations, the coherency was reasonably high at the following representative frequencies:

(i) $w_1 = 0.03$ corresponding to a fairly long period of 67 months[4]

(ii)$w_2 = 0.11$ corresponding to a medium period of 18 months

(iii) $w_3 = 0.61$ corresponding to a very short period of just over 3 months.

We use the double window technique of (7) and (8), for estimating the various quantities related to the evolutionary cross-spectrum. The double window is completely specified by the choice of two parameters viz. h and T'. So far as h is concerned , it determines the relative importance given to the resolution in the time and frequency domain . According to the well-known *Grenander Uncertainty Principle* (see Grenander (1958)), improved resolution in one domain can only be at the expense of resolution in the other. Since, no strong a priori reasons exist, to prefer resolution in a particular domain, we choose h = 7, which value gives equal weightage to the two resolutions. The truncation parameter T' is chosen by the window closing procedure outlined in Subba Rao and Tong (1973). A value of T'=55 seemed appropriate in the present context.

D. Coherency

As mentioned earlier, coherency is a measure of association between pairs of series at various frequencies. In Table 1 we present separate panels for the coherency in the pre-1991 and post-1991 periods. Financial liberalisation

[4] Any smaller frequency would be difficult to analyse in view of the well-known difficulties of estimating spectra in the neighbourhood of the origin.

was undertaken on a significant scale in the structural reforms process, which was initiated in India in 1991. It was felt that financial liberalisation would have an important bearing on the potency or otherwise of monetary policy. The two major conclusions to emerge were the following:

(i) The association of both m1 and m3 with g as well as p is significantly lower in the post-1991 period than in the earlier period. This is quite understandable, since it is generally felt that the emergence of alternative money substitutes with financial innovations, weakens the relationship of money supply to the other sectors of the economy.

(ii) The long run, as well as, the short run impact on output and prices is higher for m1, than for m3. In the medium term, however, the price impact of m1 is higher than that of m3, whereas the output impact is somewhat lower. Thus, in India, m1 seems overall to bear a closer association with output and prices than m3. This finding seems to question the wisdom behind the monetary authorities' (Reserve Bank of India's) traditional focus on M3 as a reference point for their monetary policy considerations.

E. Gain Spectrum

The gain spectrum between X (t) and Y(t) is akin to a regression coefficient and (as the data is in logs) may be further interpreted as an elasticity, measuring the responsiveness in X(t) to changes in Y(t) frequency-wise. Unlike the evolutionary coherency, the evolutionary gain spectrum varies with t. Nevertheless, with a view towards economy of presentation , we only display averages of the evolutionary gain spectra (computed, as mentioned above, at six-monthly intervals) for the pre- and post-liberalisation periods in Table 2. The one noteworthy feature to emerge from that table is the following.

(i) m3 has a very marginal impact (at all the three frequencies considered) on both g and p. This, in conjunction with the conclusions on coherency, imply that m3 not only has a weak association with output growth and inflation, it would also require substantial changes in m3 to produce any visible impacts on g and p. This casts further doubts on the suitability of m3 as a monetary policy instrument.

6. GROUP DELAY : SOME NON-PARAMETRIC RESULTS

As mentioned earlier , the group delay has a direct interpretation in terms of lags . *With reference to the terminology introduced earlier, the group delay (26) measures the lag from the series Y(t) to series X(t), with negative signs being interpreted as leads.* The group delay was estimated with both the quadratic as well as the Gaussian weight functions using the value of 0.2 for the bandwidth parameter k. However , the two results were substantially similar and hence only the results pertaining to the quadratic window are considered [5]. The detailed results have been suppressed for brevity's sake. Several interesting questions pose themselves in this context. Firstly, do the various leads/lags show an increasing trend in either epoch or are they purely random? In case they are purely random in both epochs, are their means and variances over the two epochs significantly different? Our

[5] Priestley & Chao (1972) indicate that the quadratic window has superior asymptotic properties as compared to the Gaussian window.

methodology has the added advantage that we can conduct a frequency-wise analysis of these issues.

Since the distributions of the group delays (in contrast to the phase) are not known, there is little sense in testing the above hypotheses via parametric methods. Non-parametric methods, in spite of their rough and ready appearance, are usually more appropriate in these situations, especially in view of their known robustness to specification errors in the underlying samples. There is a bewildering array of non-parametric tests for randomness in the literature, and any particular choice is largely a matter of taste. The tests by Foster & Stuart (1954) have been used earlier in the context of the phase by Granger & Hatanaka (1964) and we follow their lead here. The four test statistics introduced by Foster & Stuart (op.cit) are d,d',s and D and may be briefly described as follows.

For a given time series, an observation is called a lower (upper) record if it is smaller (greater) than all preceding observations in the series.We define the scores:

U(r) = 1, if the r-th observation is an upper record and U(r)= 0 otherwise.

L(r) = 1, if the r-th observation is a lower record and L(r) = 0 otherwise

In the case of ties, the ranking is done by a random permutation of their serial order—a procedure which preserves the optimum properties of the tests.

We now define

$$s = \sum_{r=2}^{n} \{U(r) + L(r)\} \qquad (31)$$

$$d = \sum_{r=2}^{n} \{U(r) - L(r)\} \qquad (32)$$

The quantity d' is defined analogously to d but by reversing the serial order of the observations viz. by counting backwards.The statistic D is now defined as

D =d-d' (33)

Foster & Stuart (op.cit.) further demonstrate the asymptotic normality and independence of s and d

$$s \approx N[m, s_1^2] \qquad (34)$$

$$d \approx N[0, s_2^2] \qquad (35)$$

where

$$m = 2\ln(n) - 0.8456 = s_2^2 \qquad (36)$$

$$s_1^2 = 2\ln(n) - 3.4253 \qquad (37)$$

Additionally they also tabulate the exact distributions for small values of n. The statistic D is also asymptotically normal with mean 0 and a rather complicated expression for the variance (which has been tabulated by Foster & Stuart (op.cit.) for some typical sample sizes).

Both the statistics D and d test the null of randomness against the alternative of a trend in the mean, whereas the statistic s tests the same null but against the alternative of a change in the dispersion of the series. Further, D seems to exhibit more power than d- a fact which is useful in analysing situations where the two statistics yield conflicting results.

The results of the non-parametric exercise are presented in Table 3, where in the event of conflict between d and D, we have favoured the latter's inference but inserted a (?) to remind us of the conflict in verdict.

As mentioned earlier, the variation in monetary policy lags could be either systematic or random. Table 3 indicates that about 5 cases out of a total of 12 could be characterized by purely random lags in the pre-liberalisation period and in the post-liberalisation period we have 6 such cases[6]. Further, the number of cases in which lags remain random in both periods is just 2. These results are too mixed to permit definite conclusions, unless a substantial amount of further data becomes available on some of the factors influencing lags, referred to earlier.

Table 4 makes a comparison between the means and variances of the leads/lags over the two epochs of interest using the Kruskall-Wallis statistic (H) and the Siegel-Tukey statistic (Z). This immediately leads to the following conclusion:

(i) The general theoretical expectation (see e.g. Vernon (1977)) that monetary policy lags should lengthen in the process of financial innovation is largely repudiated by the data. The minority viewpoint that lags become shorter in the process of deregulation because of increasing integration of asset markets (see e.g. Gabb and Mullineux

(1995)) gets even less support. By and large, financial innovation tends to leave the mean value of lags unchanged, though it seems to lead to greater variability in the lags.

A feature common to all the lead/lag relationships of our analysis, is the frequent alteration of signs i.e. there are periods when money suply is lagging output and/or prices and *vice versa*. These may be classified respectively as periods of pasive and pro-active monetary policy. Additionally, it is possible to distinguish (on the basis of our frequency-wise analysis) between short, medium and long-run stances (corresponding to the three frequencies we have singled out for attention). A fact, well-known to all observers of central banks' actions, is the often varying monetary policy stances corresponding to different runs- thus a long-run contractionary stand is often accompanied by a short-run expansionary stance.
Harding & Pagan (2000) have introduced a *concordance index* in the context of business cycle analysis and the idea can be replicated in our context too. Thus, for any pair of series, we may define *a concordance index* as simply the proportion of observations with the same sign for the two series. It is not clear, however, that the distribution theory developed by Harding & Pagan (op.cit.), is necessarily applicable to our situation and therefore our use of the index is somewhat informal. But even this informal usage is instructive. We can, on the one hand, examine whether a specific money supply variable (m1 or m3) is pro-active or otherwise, vis-à-vis both g and p, and on the other, we can also see whether m1 and m3 share the same stance with respect to g (or p). From Table 5, we garner the following two additional conclusions:

[6] By *purely random*, we mean absence of trend together with unchanging variance.

(ii) Both types of concordance are reasonably high, though they are higher in the pre-liberalisation era.

(iii) The concordances are higher at the frequencies corresponding to the longer run, indicating greater policy cohesion in the long-run, while allowing for some “blips” in the short run.

The high concordance makes it meaningful to distinguish between episodes of passive monetary policy and pro-active monetary policy .We (rather arbitrarily) speak of a common monetary stance w.r.t. g (or p) whenever m1 and m3 are either both leading or both lagging g (or p) for at least 4 consecutive 6-monthly periods at any specific frequency. Table 6 presents the major episodes of monetary policy stance decomposed into short, medium and long runs.

Finally, we turn to the issue of monetary policy lags and the *New Keynesian Phillips curve*. Since the curve is essentially exhibiting a possible short-run trade-off, the relevant frequencies from our point of view are w_2 and w_3 (corresponding, as noted above, to cycles of 18 months and 3 months respectively). If we adopt the test outlined in the Proposition of Section 2, we notice that overall, the support for the curve is weak. Out of the 46 time periods at which our evolutionary spectral computations have been reported, the conditions of the Proposition are verified for only 7 periods for m1, and for 8 periods for m3, at the frequency w_2 .The corresponding figures for the higher frequency w_3 are somewhat better at 15 for m1, and 12 for m3. Neither set of figures can be viewed as evidence in favour of the existence of a *New Keynesian Phillips curve* either in the short-run or even the very short-run.

7.CONCLUSIONS

Monetary policy lags, though of fundamental importance to the debates on the role and effectiveness of monetary policy , have received relatively little attention in the literature owing to the lack of appropriate statistical techniques of analysis. Earlier attempts to tackle this problem have been invariably in the regression framework or in its more sophisticated VAR variants. These approaches implicitly take the lag length as fixed but only the lag coefficients as time varying, when as a matter of fact both are likely to be time-varying. The technique of evolutionary spectrum that we have used in this paper is tailor-made to tackle this problem. We can claim at least three major advantages on its behalf.

(i) It treats both the lag length and lag coefficients as variable over time. Both these can be estimated at every point of time – the lag length being obtained from the evolutionary phase spectrum and the lag coefficients being estimated from the evolutionary gain spectrum. In addition the significance of the association can be tested via appeal to the coherency spectrum.

(ii) Secondly, the lag structure can also be decomposed frequency -wise. This is important in practice because monetary policy has both short run and long term ramifications, which may be fundamentally different . Regression analysis is not designed to separate out the short term and the long term effects

(iii) The power characteristics of these tests have been studied by Nachane (1997) and have been remarked on rather favourably.

Our analysis has thrown up several conclusions of interest in the context of Indian monetary policy.These have already been discussed in detail in

Sections 5 and 6. The two broad features to emerge from that discussion are the following:

(i) Friedman's original contention of the lags in monetary policy being long and variable is substantially borne out by our analysis. His conclusion of the possible destabilising role of a fine-tuning monetary policy thus applies with equal force in the Indian context. The further question of whether monetary policy should then be attuned to other goals such as exchange rate management or public debt management, becomes an issue for debate

(ii) Some light is also thrown on the contentious issue of the effects of financial liberalisation on monetary policy lags. We find that, by and large, the average length of the monetary policy lags have been left unaltered by financial liberalisation. The variability of lags, however, seems to have increased significantly in the context of financial liberalisation in India since 1991.

(iii) Finally, (in the Indian context), our analysis concludes strongly against the existence of any short-run trade-offs , associated with a *New Keynesian Phillips curve*, which can be exploited by a central banker.

Our analysis needs to be supplemented in at least three directions. Firstly, the various entities need to be recorded at every time point (instead of twice a year as we have done). This can be very easily done within the existing framework. Secondly, to probe further into the elements of monetary transmission we need to study the impacts of the monetary variables on the various sectors of IIP as well as WPI. Finally, IIP is a very imperfect proxy for GDP and the analysis can only be really meaningful when high-frequency GDP estimates are available for India. This, unfortunately, is an area which has received little attention from either the government or academic circles in India.

References

1. Akerlof, G.A. and J.L.Yellen (1985) "A near-rational model of the business cycle with wage and price inertia" Quarterly Journal of Economics, Vol.100 (Supplement), p.823-838.

2. Anderson,L.C. and J.L.Jordan (1968)" Monetary and fiscal actions: A test of their relative importance in economic stabilisation" Federal Reserve Bank of St.Louis Review, Vol.50, Nov, p.11-24.

3. Anderson, L.C. and D.S.Karnosky (1972) "The appropriate time frame for controlling monetary aggregates : The St. Louis evidence" in Controlling Monetary Aggregates II: The Implementation FRB of Boston Conference Series, # 9

4. Ando, A., E.C.Brown, R.Solow and J.Kareken (1963) "Lags in fiscal and monetary policy" in Commission on Money and Credit Stabilisation Policies, Prentice Hall, Englewood Cliffs, NJ.

5. Ball, L. (1994) "Credible disinflation with staggered price setting" American Economic Review, Vol.84, p.282-289.

6. Batini, N. and A.Haldane (1999) "Forward looking rules for monetary policy" in J.B.Taylor (ed.) Monetary Policy Rules, University of Chicago Press

7. Blanchard, O.J. and N.Kiyotaki (1987) " Monopolistic competition and the effects of aggregate demand" American Economic Review, Vol.77, p.647-666.

8. Beaulieu, J.J. and J.A.Miron (1993) "Seasonal unit roots in aggregate US data" Journal of Econometrics, Vol.55, p.305-328.

9. Bernanke B.and M.Gertler, (1995) " Inside the black box : The credit channel of the monetary policy transmission " Journal of Economic Perspectives, Vol.9 (4), p.27-48.

10. Bernanke, B. and M. Gertler (2000) "Monetary policy and asset price volatility" NBER Working Paper # 7559

11. Bodkin , R.G. and K.S.Murthy (1973) "The orders-shipment mechanism in Canadian producer industries" Journal of American Statistical Association, Vol.68, p.297-305.

12. Bordo, M.D. and E.U.Choudhry (1982) " Currency substitution and the demand for money : Some evidence for Canada" Journal of Money, Credit and Banking Vol.14, p.48-57.

13. Bryan , M.F and W.T. Gavin (1994) " A different kind of money illusion: The case of long and variable lags " Journal of Policy Modelling, Vol.16, p.529-540.

14. Cargill, T.F. and R.A.Meyer (1972) "A spectral approach to estimating the distributed lag relationship between long and short term interest rates" International Economic Review, Vol.13, p.223-238.

15. Cecchetti,S.G., H.Genberg, J.Lipsky and S.Wadhwani (2000) : "Asset prices and Central Bank policy" CEPR, London

16. Clarida, R., M.Gertler and J.Gali (1999) "The science of monetary policy : A new Keynesian perspective" Journal of Economic Literature, Vol.37, p.1661-1707.

17. Chan, W.Y.T and Tong H (1975) "A simulation study of the estimation of evolutionary spectral functions", Applied Statistics, Vol.24, p.333-41.

18. Culbertson, J. (1960) "Friedman on the lag in the effect of monetary policy" Journal of Political Economy, Vol.68, p.617-621.

19. Culbertson , J (1961)" The lag in effect of monetary policy: Reply" Journal of Political Economy , vol.69, p.467-477.

20. Cukierman,A., Z.Hercovitz and L.Leiderman (ed.) (1992) Political Economy, Growth and Business Cycle, MIT Press, Cambridge

21. Fishman, G.S. (1969) Spectral Methods in Econometrics, Harvard University Press, Cambridge Mass.

22. Foster, F.G. and A.Stuart (1954) "Distribution-free tests in time-series based on the breaking of records" Journal of the Royal Statistical Society, Ser.B Vol.16(1), p.1-22

23. Friedman , M. (1961)" The lag in effect of monetary policy" Journal of Political Economy, Vol 69, p.447-466.

24. Fromm, G. and L.R.Klein (1975) "The NBER/NSF model comparison seminar : An analysis of results" in L.R.Klein and E.Burmeister (ed) Econometric Model Performance, University of Pennsylvania Press,Philadelphia, p.380-407

25. Fuhrer, J. and G.Moore (1995) " Inflation persistence" Quarterly Journal of Economics, Vol.110 , p.127-160.

26. Gabb, W. and A.Mullineux (1995) "Financial innovation, monetary aggregates and monetary policy in the U.K. and Germany" University of Birmingham, Department of Economics, D.P. # 95-17

27. Granger C.W.J and M..Hatanaka (1964) Spectral Analysis for Economic Time Series, Princeton University Press, Princeton, New Jersey.

28. Grenander, U. (1958) "Resolvability and reliability in spectral analysis" Journal of the Royal Statistical Society, Series B, Vol.20 , p.152-157.

29. Hannan, E.J and P.J.Thomson (1971) " The estimation of coherence and group delay" Biometrika, Vol.58, p.469-481.

30. Harding, D. and A.Pagan (2000) "Synchronization of cycles" (mimeo.)

31. Hylleberg S., R.Engle, C.W.J.Granger and B.S.Yoo (1990) "Seasonal integration and cointegration" Journal of Econometrics, Vol.44, p.215-238.

32. Kanji, G. (1999) 100 Statistical Tests, Sage Publications, London

33. Kareken, J. and R.M.Solow (1963) "Lags in monetary policy" in Stabilisation Policies, Commission on Money & Credit, Prentice-Hall, Englewood Cliffs, p.14-96.

34. Kaufman, G. and R.Laurent (1970) "Simulating policy strategies under two alternative monetary policy regimes" Quarterly Review of Economics & Business, vol. 4 (Winter), p.51-64.

35. Levin,A., W.Volker and J.C.Williams (1999) "Robustness of simple monetary policy rules under model uncertainty" in J.B.Taylor (ed.) Monetary Policy Rules, University of Chicago Press

36. Lucas, R. (1976) "Econometric policy evaluation : A critique" Carnegie-Rochester Conference Series on Public Policy Vol.1, p.19-46.

37. Mankiw, N.G. (1985) "Small menu costs and large business cycles : A macroeconomic model of monopoly" Quarterly Journal of Economics, Vol.100, p.529-537.

38. Mankiw, N.G. (2000) "The inexorable and mysterious trade-off between inflation and unemployment" NBER Working Paper Series # 7884

39. Mayer, T. (1967)″The lag in the effect of monetary policy: Some criticisms" Western Economic Journal Vol.5, p.324-342.

40. McCallum, B. (1997) "Comment" NBER Macroeconomics Annual, Vol.12, p.355-359.

41. Melard G., (1985)" An example of the evolutionary spectrum theory" Journal of Time Series Analysis vol.6, p.81-90.

42. Mishkin, F.S. (1995) ″Symposium on the monetary transmission mechanism" Journal of Economic Perspectives, Vol 9(4), Fall, p.3-10.

43. Montiel, P.J. (1991) ″The transmission mechanism for monetary policy in developing countries" IMF Staff Papers, vol 30(1), p.83-108.

44. Nachane, D.M. (1997) ″Purchasing power parity: An analysis based on the evolutionary spectrum" Applied Economics, Vol.29, p.1515-1524.

45. Nachane D.M. and D.Ray (1993) "Modelling exchange rate dynamics: New perspectives from the frequency domain" Journal of Forecasting, Vol.12(5), p.379-394.

46. Page,C.H (1952) "Instantaneous Power Spectra" Journal of Applied Physics, Vol.23, p.103-106.

47. Perryman, M.R. (1980) "Some evidence regarding the lag in the initial countercyclical response of monetary policy " Nebraska Journal of Economics and Business, Vol.19, p.65-71.

48. Poole, W. (1975) "The relationship of monetary decelerations to business cycle peaks : Another look at the evidence" Journal of Finance Vol.30, p.697-712.

49. Priestley, M.B.(1965) "Evolutionary spectra and non-stationary processes" Journal of the Royal Statistical Society, Series B, Vol.27, p.204-237.

50. Priestley, M.B. (1981) Spectral Analysis and Time Series Academic Press, London

51. Priestley, M.B. (1988) Non-linear and Non-stationary Time Series Analysis" , Academic Press, New York.

52. Priestley, M.B. and M.T.Chao (1972) "Non -parametric function fitting" Journal of the Royal Statistical Society Vol.34, Series B , p.385-392.

53. Priestley,M.B. and H.Tong (1973)" On the analysis of bivariate non-stationary processes" Journal of the Royal Statistical Society, Vol.35, Series B, p.153-166.

54. Purvis, D.D. (1990) "The Bank of Canada and the Pursuit of Price Stability" In N.York (ed) Zero Inflation: The Goal of Price Stability, C.D.Howe Institute, Toronto.

55. Reserve Bank of India, Annual Report 1998-99, Chapter III

56. Roberts, J.M.(1995) "New Keynesian economics and the Phillips curve" Jornal of Money, Credit and Banking Vol.27, p.975-984.

57. Rosenbaum, M.S. (1985)" Lags in the effect of monetary policy" Federal Reserve Bank of Atlanta Economic Review, November, p.20-33.

58. Sargent, T.J. (1976) "The observational equivalence of natural and unnatural rate theories of macroeconomics" Journal of Political Economy, Vol 84(3), p.631-640.

59. Subba Rao, T. and H.Tong (1973) "On some tests for the time-dependence of a transfer function" Biometrika, Vol.60, p.589-597.

60. Sveshnikov, A.G.and A.N.Tikhonov (1971) The Theory of Functions of a Complex Variable, MIR publishers, Moscow.

61. Tanner , J.E. (1979) “Are the lags in the effects of monetary policy variable?” Journal of Monetary Economics, Vol.5,p.105-121.

62. Taylor,J.B. (2000) “Alternative views of the monetary transmission mechanism: What difference do they make for monetary policy?” Oxford Review of Economic Policy (forthcoming)

63. Tischendorf, J.A. and M.T.Chao (1970) "Statistical properties of estimates of an integral" Bell Telephone Laboratories (mimeo)

64. Tjostheim, D.(1976) “Spectral generating operators for non-stationary processes”, Advances in Applied Probability, Vol.8, p.563-567.

65. Tong, H. (1972) Some problems in the spectral analysis of bivariate non-stationary stochastic processes, Ph.d Thesis, University of Manchester.

66. Tucker , D.P. (1966) "Dynamic income adjustment to money supply changes" American Economic Review, Vol 56(3), p.433-449.

67. Uselton, G.C. (1974) Lags in the Effects of Monetary Policy : A Non-Parametric Approach, Marcel Dekker, New York.

68. Vernon, J. (1977) “Money demand, interest elasticity and monetary policy effectiveness” Journal of Monetary Economics, Vol.3, p.179-190.

69. Warburton, C (1971) “Variability of the lag in the effect of monetary policy 1919- 1965” Western Economic Journal, Vol.9, p.115-133