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GRANGER-CAUSALITY AND STABILIZATION POLICY

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ABSTRACT

This paper aims to provide a stochastic, rational expectations extension of Tobin's "Money and Income; Post Hoc Ergo Proper Hoc?". It is well-known that money may Granger-cause real variables even though the joint density function of the real variables is invariant under changes in the deterministic components of the monetary feedback rule. The paper shows that failure of money to Granger-cause real variables does not preclude a stabilization role of money. In a number of examples the conditional second moment of real output is a function of the deterministic components of the monetary feedback rule. Yet money fails to Granger-cause output ("in mean" and "in variance"). In all these models money is a pure stabilization instrument: superneutrality is assumed. If the analysis is extended to "structural" or "allocative" instruments such as fiscal instruments, the conclusion is even stronger. Failure of these policy instruments to Granger-cause real variables is consistent with changes in the deterministic parts of the policy feedback rules being associated with changes in the conditional means of the real variables.

Granger-causality tests are tests of "incremental predictive content". They convey no information about the invariance of the joint density function of real variables under changes in the deterministic components of policy feedback rules.

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1. Introduction

It is generally recognized that if a set of monetary and fiscal policy variables Granger-cause [1/] real economic variables, this does not imply that alternative deterministic (and known) rules for determining the values of these policy instruments will alter the joint density function of the real variables.[2/] It is, however, also asserted that "failure of monetary and fiscal policy variables to cause unemployment and other real variables is sufficient to deliver classical policy implications (Sargent [1976, p. 222]). Cuddington ([1980], p. 539) also argues that "... various "classical" policy implications emerge from models in which the conditional expectations of all real variables are invariant with respect to government policy instruments. This is equivalent to the statistical hypothesis that the simultaneously determined variables of the economic model are jointly exogenous with respect to all policy variables." It is easily demonstrated that failure of "allocative" or "structural" policy instruments to Granger-cause real variables is quite consistent with the conditional expectations of the real variables not being invariant with respect to alternative deterministic feedback rules for the policy instruments. A simple example is given in Section 6.

Perhaps the proposition of Sargent and Cuddington that failure of monetary and fiscal policy instruments to Granger-cause real variables implies that the conditional means of real variables are invariant with respect to monetary and fiscal policy, is meant to apply only to "pure" stabilization policy instruments. These are policy instruments that can only influence deviations of real variables from their equilibrium, natural or "full information" values without being able to alter these natural values themselves. This is in contrast to "structural" or "allocative" policy instruments that can influence the natural values. If the familiar monetary superneutrality issues do not arise, monetary policy may qualify as pure stabilization policy. The only other candidate would seem to be changes in the borrowing-lump-sum taxation mix for a given level and composition of government spending on goods and services. Sections 2, 3, 4 and 5 analyse the relationship between monetary stabilization policy and Granger-causality. For such a pure stabilization policy the proposition of Sargent and Cuddington concerning the invariance of the conditional means of real variables is correct. If "classical policy implications" only means inability to influence the conditional means of real variables, the policy conclusions to be drawn from a failure of monetary (and fiscal) stabilization instruments to Granger-cause real variables are "classical". The conclusions that are drawn appear, however, to be more sweeping than this and amount to a rejection of policy activism and of a role for countercyclical or stabilization policy "...government manipulations of monetary and fiscal policy variables have no predictable effects on unemployment, output or the interest rate and hence are useless for pursuing countercyclical policy." (Sargent [1976, p. 208]).

In Sections 2 to 5 I show that the stronger structural neutrality or policy neutrality proposition that the joint density function of the real variables is invariant under alternative deterministic policy rules is not confirmed by a failure of pure stabilization instruments to Granger-cause the real variables. I start from the premise that the case for activism in stabilization policy, defined as the use of closed-loop or feedback rules for monetary (and fiscal) policy instruments, hinges not on the invariance of the <u>conditional means</u> of real variables with respect to these instruments but on the invariance of <u>higher conditional moments</u>. Specifically, stabilization policy or countercyclical policy is about fluctuations around equilibrium. It is aimed at influencing deviations of real variables from their conditional means; it therefore concerns the conditional variances of output, employment, etc. The example worked out in Sections 2 and 3 shows how failure of money to Granger-cause output is consistent with monetary feedback rules being capable of stabilizing output perfectly at its (policy-invariant) "natural" level. This ability to influence the conditional variance of output exists even though money fails to Granger-cause output "in variance", as well as "in mean" (Granger [1980]).

This paper follows up on a statement by Sims that "The fact that policy variables are always in one sense causally prior to the other variables in a model is sometimes assumed to make it likely that they are Granger-prior, i.e. exogenous, in data used for estimation" (Sims [1979, pp. 105-106]).[3/] It therefore addresses an issue very similar to the one that concerned Tobin in his paper "Money and Income: Post Hoc Ergo Propter Hoc?" (Tobin [1970]) and can indeed be viewed as a stochastic, rational expectations extension of Tobin's analysis. To investigate the general validity of the view referred to by Sims, Sections 2 and 3 analyse a model with one real variable, output, and one nominal instrument, the money supply. It has the following properties:

a) The public sector and the private sector have identical information sets in each period.

b) A deterministic monetary feedback rule relates the money supply m in the current period, t, to past information only. If I_t denotes the information set conditioning expectations in period t, we have $m_t = f(I_{t-i}) \quad i \geqslant 1$.

c) In the model any degree of stabilization of output, including 'perfect' stabilization, can be achieved by relating m_t to I_{t-1} or to any I_{t-j}, $j > 1$.

d) Money does not Granger-cause output but output Granger-causes money.

e) While the conditional mean of output is invariant under alternative deterministic monetary rules, the conditional variance of output is, as suggested by (c), a function of the monetary rule. Feedback rules relating the current money supply to information arbitrarily far in the past can stabilize output perfectly either at its "*ex ante*" or at the *"ex-post"* natural level. The mechanism that permits this perfect stabilization is the effect on current output not of current and past values of the money supply but of (revisions in) anticipated future values of the money stock. The perfect stabilization result is specific to the model. The proposition that the conditional (and unconditional) second moments of real variables can be functions of the knownparameters of deterministic monetary feedback rules when money fails to Granger-cause these real variables holds for all models whose specification includes anticipations of future values of endogenous variables conditioned at different dates (see Turnovsky [1980], Weiss [1980], Buiter [1980, 1981, a, b, c]).

In Section 4 the existence of a potential stabilization role for an "automatic monetary stabilizer" is shown to be consistent with failure of money to Granger-cause output. Monetary feedback rules are also known to affect the density function of real variables in Fisher-Phelps Taylor models with long-term open-loop nominal contracts. It again is not necessary for money to Grange-cause output, as shown in Section 5.

The principal conclusion is the following. It is already familiar that for stabilization policy instruments to Granger-cause real variables is not sufficient to conclude that alternative deterministic stabilization policy rules alter the behaviour of real variables. This paper demonstrates that for stabilization policy instruments to fail to Grange-cause real variables is not sufficient to conclude that stabilization policy rules cannot alter the behaviour of the real economy.

2. Monetary feedback rules and output stabilization in a simple stochastic model

2a) The Model

A simple stochastic macroeconomic model is given in equations (1) and (2).

$$(1)\quad y_t = \beta_1\left(p_t - E(p_t|I_{t-1})\right) + \beta_2\, y_{t-1} + u_t^y \qquad \beta_1,\ \beta_2 \geq 0;\quad \beta_2 < 1$$

$$(2)\quad m_t - p_t = \alpha_1\, y_t - \alpha_2\left(E(p_{t+1}|I_t) - p_t\right) + u_t^m \qquad \alpha_1,\ \alpha_2 > 0$$

Equation (1) is a Sargent-Wallace [1975] supply function. Output, y_t , depends on the discrepancy between the current price level, p_t , and its value anticipated in the previous period. E is the mathematical expectation operator. Because of adjustment costs output also depends on lagged output. In equation (2), the demand for real money balances is an increasing function of output and a decreasing function of the expected future rate of inflation. All variables are in logarithms. u_t^y and u_t^m are normal, mutually serially independent and identically distributed random disturbances. They are also assumed to be contemporaneously independent. The information set in period t , I_t , consists of all past and current values of the endogenous variables (y and p) and of m . It therefore also includes the current and past values of u_t^y and u_t^m which can be inferred directly, given y_t , p_t and m_t . The model structure, including $E(u_t^y)^2 = \sigma_y^2$ and $E(u_t^m)^2 = \sigma_m^2$ also belongs to the information set.

It is essential for the proposition established in this Section, that the model contain expectations of future endogenous variables conditioned at different dates. In (1) and (2) this condition is satisfied because of the presence of $E(p_t|I_{t-1})$ and $E(p_{t+1}|I_t)$. Monetary feedback rules based on past information are irrelevant for the behaviour of real output in the Sargent and Wallace model because in that model the price level expectation for period $t + 1$ is, like the price level expectation for period t , conditional on I_{t-1} . In the present model too, monetary policy neutrality prevails if $E(p_{t+1}|I_t)$ is replaced by $E(p_{t+1}|I_{t-1})$. There are some reasons for preferring the specification involving $E(p_{t+1}|I_t)$. Current output may e.g. be affected by past expectations because of long-term labour contracts, while efficient financial markets only reflect current behaviour including currently formed expectations.

More important than the relative merits of alternative simple macromodels, both of which leave much to be desired, is the formal logic of the argument which is independent of the economic connotations of y_t, p_t and m_t.

I shall refer to the level of output that obtains when $p_t = E(p_t | I_{t-1})$ as the *"ex post"* natural level of output or y^*. I.e.

$$(3a) \qquad y_t^* = \beta_2 y_{t-1} + u_t^y .$$

The *"ex-ante"* natural level of output y^{**} is the level of output that would prevail in the absence of any uncertainty, i.e.

$$(3b) \qquad y_t^{**} = \beta_2 y_{t-1}$$

From (1) and (2) we can solve for p_t

$$(4) \qquad p_t = \frac{1}{\Pi_1} m_t + \frac{\alpha_1 \beta_1}{\Pi_1} E(p_t | I_{t-1}) + \frac{\alpha_2}{\Pi_1} E(P_{t+1} | I_t) - \frac{\alpha_1 \beta_2}{\Pi_1} y_{t-1} - \frac{1}{\Pi_1}(\alpha_1 u_t^y + u_t^m)$$

where

$$(5) \qquad \Pi_1 = 1 + \alpha_2 + \alpha_1 \beta_1$$

From (4) it follows that

$$(6) \qquad p_t - E(p_t | I_{t-1}) = \frac{1}{\Pi_1} \Big[m_t - E(m_t | I_{t-1}) \Big] + \frac{\alpha_2}{\Pi_1} \Big[E(p_{t+1} | I_t) - E(p_{t+1} | I_{t-1}) \Big] - \frac{1}{\Pi_1} (\alpha_1 u_t^y + u_t^m)$$

Using (4) we find that, for $i \geq 1$

$$(7)\quad E(p_{t+i}|I_t) - E(p_{t+i}|I_{t-1}) = \frac{\alpha_2}{1+\alpha_2}\left[E(p_{t+i+1}|I_t) - E(p_{t+i+1}|I_{t-1})\right] + \frac{1}{1+\alpha_2}\left[E(m_{t+i}|I_t) - E(m_{t+i}|I_{t-1})\right] - \beta_2^i \frac{\alpha_1}{1+\alpha_2}\left[\beta_1\left(p_t - E(p_t|I_{t-1})\right) + u_t^y\right]$$

Solving this difference equation forward in time we obtain:

$$(8)\quad E(p_{t+1}|I_t) - E(p_{t+1}|I_{t-1}) = -\frac{\alpha_1}{1+\alpha_2}\left[\beta_1\left(p_t - E(p_t|I_{t-1})\right) + u_t^y\right]\sum_{j=0}^{\infty}\left(\frac{\alpha_2}{1+\alpha_2}\right)^j \beta_2^{j+1} + \frac{1}{1+\alpha_2}\sum_{j=0}^{\infty}\left(\frac{\alpha_2}{1+\alpha_2}\right)^j\left[E(m_{t+1+j}|I_t) - E(m_{t+1+j}|I_{t-1})\right] + \lim_{N\to\infty}\left(\frac{\alpha_2}{1+\alpha_2}\right)^N\left[E(p_{t+1+N}|I_t) - E(p_{t+1+N}|I_{t-1})\right]$$

If $\alpha_2 > 0$, $0 \leq \beta_2 < 1$ and $\lim_{N\to\infty} E(p_{t+1+N}|I_t)$ is bounded, (8) becomes

$$(9)\quad E(p_{t+1}|I_t) - E(p_{t+1}|I_{t-1}) = -\frac{\alpha_1\beta_2}{1+\alpha_2(1-\beta_2)}\left[\beta_1\left(p_t - E(p_t|I_{t-1})\right) + u_t^y\right] + \frac{1}{1+\alpha_2}\sum_{j=0}^{\infty}\left(\frac{\alpha_2}{1+\alpha_2}\right)^j\left[E(m_{t+1+j}|I_t) - E(m_{t+1+j}|I_{t-1})\right]$$

Substituting (9) into (6) yields:

$$(10)\quad p_t - E(p_t|I_{t-1}) = \frac{1+\alpha_2(1-\beta_2)}{\Pi_1[1+\alpha_2(1-\beta_2)] + \alpha_1\alpha_2\beta_2}[m_t - E(m_t|I_{t-1})]$$

$$+ \frac{1+\alpha_2(1-\beta_2)}{\Pi_1[1+\alpha_2(1-\beta_2)] + \alpha_1\alpha_2\beta_2}\left(\frac{\alpha_2}{1+\alpha_2}\right)\sum_{j=0}^{\infty}\left(\frac{\alpha_2}{1+\alpha_2}\right)^j[E(m_{t+1+j}|I_t) - E(m_{t+1+j}|I_{t-1})]$$

$$- \frac{[1+\alpha_2(1-\beta_2)]}{\Pi_1[1+\alpha_2(1-\beta_2)] + \alpha_1\alpha_1\beta_2}\left[\alpha_1\left(\frac{1+\alpha_2}{1+\alpha_2(1-\beta_2)}\right)u_t^y + u_t^m\right]$$

The price forecast error for period t is a function of the revision, between periods $t-1$ and t, in the forecasts of the money stocks for period t and for all later periods. In the Sargent-Wallace model, with the expectation of p_{t+1} conditioned at $t-1$ rather than at t as in equation (2), the price forecast error for period t depends only on $m_t - E(m_t|I_{t-1})$ and not on $E(m_{t+i}|I_t) - E(m_{t+i}|I_{t-1})$ for $i \geq 1$. In the model of equations (1) and (2), $p_t - E(p_t|I_{t-1})$ and therefore y_t are, according to (6), functions of $E(p_{t+1}|I_t) - E(p_{t+1}|I_{t-1})$ and therefore, according to equation (8), of $E(m_{t+i}|I_t) - E(m_{t+i}|I_{t-1})$, $i \geq 1$. Current and past values of the money stock will, if the money supply is a linear function of only past information, not affect $p_t - E(p_t|I_{t-1})$ or y_t. Future money supplies related to current information will however affect $p_t - E(p_t|I_{t-1})$ and y_t. These issues are discussed further in Turnovsky [1980], Buiter [1980, 1981 a, b, c] and Buiter and Eaton [1980].

Using (10) and (1) the behaviour of output is given by:

$$(11)\quad y_t = \beta_2 y_{t-1} + \beta_1 \frac{\beta_1[1+\alpha_2(1-\beta_2)]}{\Pi_1[1+\alpha_2(1-\beta_2)] + \alpha_1\alpha_2\beta_2}[m_t - E(m_t|I_{t-1})]$$

$$+ \frac{\beta_1[1+\alpha_2(1-\beta_2)]}{\Pi_1[1+\alpha_2(1-\beta_2)] + \alpha_1\alpha_2\beta_2}\left(\frac{\alpha_2}{1+\alpha_2}\right)\sum_{j=0}^{\infty}\left(\frac{\alpha_2}{1+\alpha_2}\right)^j [E(m_{t+1+j}|I_t) - E(m_{t+1+j}|I_{t-1})]$$

$$+ \left[\frac{\Pi_1[1+\alpha_2(1-\beta_2)] + \alpha_1\alpha_2\beta_2 - \alpha_1\beta_1(1+\alpha_2)}{\Pi_1[1+\alpha_2(1-\beta_2)] + \alpha_1\alpha_2\beta_2}\right]u_t^y - \frac{\beta_1[1+\alpha_2(1-\beta_2)]}{\Pi_1[1+\alpha_2(1-\beta_2)] + \alpha_1\alpha_2\beta_2}u_t^m$$

2b) <u>The effectiveness of monetary feedback rules</u>

Consider the case where monetary policy is conducted according to a non-stochastic fixed (or open-loop) rule. Under such a rule $m_t = E(m_t|I_{t-1})$, $E(m_{t+1+j}|I_t) - E(m_{t+1+j}|I_{t-1}) = 0$ for all $j \geq 0$ and the behaviour of output is given by (12)

$$(12)\quad y_t = \beta_2 y_{t-1} + \left[\frac{\Pi_1[1+\alpha_2(1-\beta_2)] + \alpha_1\alpha_2\beta_2 - \alpha_1\beta_1(1+\alpha_2)}{\Pi_1[1+\alpha_2(1-\beta_2)] + \alpha_1\alpha_2\beta_2}\right]u_t^y$$

$$- \frac{\beta_1[1+\alpha_2(1-\beta_2)]}{\Pi_1[1+\alpha_2(1-\beta_2)] + \alpha_1\alpha_2\beta_2}u_t^m$$

Now consider a deterministic monetary feedback (or closed-loop) rule that makes the money supply in period t a function of all past random disturbances.

$$(13)\quad m_t = \sum_{i=1}^{\infty} \mu_{y,i}\, u_{t-i}^y + \mu_{m,i}\, u_{t-i}^m$$

The $\mu_{y,i}$ and $\mu_{m,i}$ are the known parameters of the feedback rule. Note that, given (13), $m_t - E(m_t|I_{t-1}) = 0$ and $E(m_{t+1+j}|I_t) - E(m_{t+1+j}|I_{t-1}) = \mu_{y,j+1} u_t^y + \mu_{m,j+1} u_t^m \quad , \quad j \geq 0$.

Under the feedback rule (13) the current price forecast error and real output are given by (14) and (15) respectively.

$$(14)\quad p_t - E(p_t|I_{t-1}) = \frac{1 + \alpha_2(1-\beta_2)}{\Pi_1[1+\alpha_2(1-\beta_2)] + \alpha_1\alpha_2\beta_2}\left(\frac{\alpha_2}{1+\alpha_2}\right)\sum_{j=0}^{\infty}\left(\frac{\alpha_2}{1+\alpha_2}\right)^j$$

$$[\mu_{y,j+1} u_t^y + \mu_{m,j+1} u_t^m] - \frac{\alpha_1(1+\alpha_2)}{\Pi_1[1+\alpha_2(1-\beta_2)] + \alpha_1\alpha_2\beta_2} u_t^y$$

$$- \frac{[1+\alpha_2(1-\beta_2)]}{\Pi_1[1+\alpha_2(1-\beta_2)] + \alpha_1\alpha_2\beta_2} u_t^m$$

$$(15)\quad y_t = \beta_2 y_{t-1} + \frac{\beta_1[1+\alpha_2(1-\beta_2)]}{\Pi_1[1+\alpha_2[1-\beta_2)] + \alpha_1\alpha_2\beta_2}\left(\frac{\alpha_2}{1+\alpha_2}\right)\sum_{j=0}^{\infty}\left(\frac{\alpha_2}{1+\alpha_2}\right)^j$$

$$[\mu_{y,j+1} u_t^y + \mu_{m,j+1} u_t^m] + \left[\frac{\Pi_1[1+\alpha_2(1-\beta_2)] + \alpha_1\alpha_2\beta_2 - \alpha_1\beta_1(1+\alpha_2)}{\Pi_1[1+\alpha_2(1-\beta_2)] + \alpha_1\alpha_2\beta_2}\right] u_t^y$$

$$- \frac{\beta_1[1+\alpha_2(1-\beta_2)]}{\Pi_1[1+\alpha_2(1-\beta_2)] + \alpha_1\alpha_2\beta_2} u_t^m$$

From inspection of (14) it is clear that the authorities can eliminate completely the price forecast error by choosing the $\mu_{y,i}$ and $\mu_{m,i}$ such that

$$(16a)\quad [1+\alpha_2(1-\beta_2)]\left(\frac{\alpha_2}{1+\alpha_2}\right)\sum_{j=0}^{\infty}\left(\frac{\alpha_2}{1+\alpha_2}\right)^j \mu_{y,j+1} - \alpha_1(1+\alpha_2) = 0$$

and

$$(16b)\quad \left(\frac{\alpha_2}{1+\alpha_2}\right)\sum_{j=0}^{\infty}\left(\frac{\alpha_2}{1+\alpha_2}\right)^j \mu_{m,j+1} - 1 = 0$$

Any choices of $\mu_{y,i}$ and $\mu_{m,i}$ that satisfy (16a) and (16b) equate p_t to $E(p|I_{t-1})$. Output is equal, in each period, to its *ex post* natural value y^*, i.e.

$$(17)\quad y_t = \beta_2 y_{t-1} + u_t^y$$

It doesn't matter whether the government makes m_t respond to u_{t-1}^y and u_{t-2}^m, to u_{t-100}^y and u_{t-100}^m or to all past disturbances. Equivalent effects on the price forecast error and on output can be achieved by infinitely many different feedback rules. In what follows it is assumed for concreteness that m_t responds only to u_{t-2}^y and u_{t-2}^m. To set output equal to its *ex post* natural level we therefore choose the $\mu_{y,i}$ and $\mu_{m,i}$ such that

$$(18a)\quad \mu_{y,2} = \frac{\alpha_1(1+\alpha_2)^3}{\alpha_2^2[1+\alpha_2(1-\beta_2)]}$$

$$(18b)\quad \mu_{m,2} = \left(\frac{1+\alpha_2}{\alpha_2}\right)^2$$

$$(18c)\quad \mu_{y,i} = \mu_{m,i} = 0\ ,\ i \neq 2$$

The monetary feedback rule is now given by

$$(19)\quad m_t = \frac{\alpha_1(1+\alpha_2)^3}{\alpha_2^2[1+\alpha_2(1-\beta_2)]} u^y_{t-2} + \left(\frac{1+\alpha_2}{\alpha_2}\right)^2 u^m_{t-2}$$

The behaviour of the price level when the money supply rule is given by

$$(19a)\quad m_t = \mu_{y,2}\, u^y_{t-2} + \mu_{m,2}\, u^m_{t-1}$$

with $\mu_{y,2}$ and $\mu_{m,2}$ given by (18a, b) is derived as follows.

From (2) we see that

$$(20)\quad p_t = \frac{1}{1+\alpha_2} m_t - \frac{\alpha_1}{1+\alpha_2} y_t - \frac{1}{1+\alpha_2} u^m_t + \frac{\alpha_2}{1+\alpha_2} E(p_{t+1}|I_t)$$

Therefore, for all $i \geq 1$

$$(21)\quad E(p_{t+i}|I_t) = \frac{\alpha_2}{1+\alpha_2} E(p_{t+i+1}|I_t) + \frac{1}{1+\alpha_2} E(m_{t+i}|I_t) - \frac{\alpha_1}{1+\alpha_2} E(y_{t+i}|I_t)$$

Solving (21) forward in time we obtain, for $i = 1$

$$(22)\quad E(p_{t+1}|I_t) = \lim_{N\to\infty}\left(\frac{\alpha_2}{1+\alpha_2}\right)^N E(p_{t+1+N}|I_t) + \frac{1}{1+\alpha_2}\sum_{j=0}^{\infty}\left(\frac{\alpha_2}{1+\alpha_2}\right)^j E(m_{t+1+j}|I_t)$$
$$- \frac{\alpha_1}{1+\alpha_2}\sum_{j=0}^{\infty}\left(\frac{\alpha_2}{1+\alpha_2}\right)^j E(y_{t+1+j}|I_t)$$

From (19a) it follows that

$$(23)\; E(m_{t+1+j}|I_t) = \begin{cases} \mu_{y,2}\, u^y_{t-1} + \mu_{m,2}\, u^m_{t-1} & \text{for } j = 0 \\ \mu_{y,2}\, u^y_t + \mu_{m,2}\, u^m_t & \text{for } j = 1 \\ 0 & \text{for } j > 1 \end{cases}$$

With the monetary rule given in (19), output behaviour is governed by (17) and therefore

$$(24) \quad E(y_{t+1+j}|I_t) = \beta_2^{j+1}\, y_t \qquad \text{for } j \geq 0$$

Substituting (23) and (24) into (22) and assuming $\alpha_2 > 0$ and $0 < \beta_2 < 1$, 4/ (22) becomes

$$(25) \quad E(p_{t+1}|I_t) = \frac{1}{1+\alpha_2}(\mu_{y,2}\, u^y_{t-1} + \mu_{m,2}\, u^m_{t-1}) + \frac{\alpha_2}{(1+\alpha_2)^2}(\mu_{y,2}\, u^y_t + \mu_{m,2}\, u^m_t) - \frac{\alpha_1\beta_2}{1+\alpha_2(1-\beta_2)}\, y_t$$

Substituting (25) into (20) and using (18a, b) and (17) the price equation is:

$$(26) \quad p_t = \frac{\alpha_1(1+\alpha_2)}{\alpha_2[1+\alpha_2(1-\beta_2)]}\, u^y_{t-1} + \frac{1}{\alpha_2}\, u^m_{t-1} + \frac{\alpha_1(1+\alpha_2)^2}{\alpha_2^2[1+\alpha_2(1-\beta_2)]}\, u^y_{t-2} + \left(\frac{1+\alpha_2}{\alpha_2^2}\right) u^m_{t-2} - \frac{\alpha_1}{1+\alpha_2(1-\beta_2)}\, \beta_2\, y_{t-1}$$

This confirms the conclusion reached earlier that the monetary feedback rule (19) ensures that $p_t = E(p_t|I_{t-1})$.

Using (17), we can rewrite (26) as:

$$p_t = \frac{\alpha_1(1+\alpha_2)}{\alpha_2[1+\alpha_2(1-\beta_2)]}\, u^y_{t-1} + \frac{1}{\alpha_2}\, u^m_{t-1} + \frac{\alpha_1(1+\alpha_2)^2}{\alpha_2^2[1+\alpha_2(1-\beta_2)]}\, u^y_{t-2} + \left(\frac{1+\alpha_2}{\alpha_2^2}\right) u^m_{t-2} - \frac{\alpha_1}{1+\alpha_2(1-\beta_2)}\, \beta_2 \sum_{i=0}^{\infty} \beta_2^i\, u^y_{t-1-i}$$

With $0 < \beta_2 < 1$ the asymptotic variance of p_t will therefore be bounded.

Inspection of (15) indicates that the policy maker could instead of setting p_t equal to $E(p_t | I_{t-1})$ choose to eliminate all randomness from the output equation and thus to equate output to its *ex ante* natural level y^{**} in each period. With the $\mu_{y,i}$ and $\mu_{m,i}$ satisfying (27a) and (27b), output obeys the non-stochastic difference equation (28).

$$\text{(27a)} \quad \beta_1[1+\alpha_2(1-\beta_2)] \left(\frac{\alpha_2}{1+\alpha_2}\right) \sum_{j=0}^{\infty} \left(\frac{\alpha_2}{1+\alpha_2}\right)^j \mu_{y,j+1} + \Pi_1[1+\alpha_2(1-\beta_2)]$$

$$+ \alpha_1\alpha_1\beta_2 - \alpha_1\beta_1(1+\alpha_2) = 0$$

$$\text{(27b)} \quad \left(\frac{\alpha_2}{1+\alpha_2}\right) \sum_{j=0}^{\infty} \left(\frac{\alpha_2}{1+\alpha_2}\right)^j \mu_{m,j+1} - 1 = 0$$

$$\text{(28)} \quad y_t = \beta_2 \, y_{t-1}$$

If u_t^y represent true exogenous supply shocks, equating output to its *ex post* natural level as in (17) is probably the superior policy objective.

Contrast the behaviour of output under an open-loop monetary rule with that under the two types of feedback rules defined by (16a, b) and (27a, b), i.e. contrast (12) with (17) or (28). It is apparent that in the present model monetary feedback rules are a potentially powerful stabilization device. The density function of y_t is certainly not invariant under alternative known monetary policy rules. Let superscripts f , * and ** refer to equations (12), (17) and (28) respectively. The conditional expectation of output is the same for (12), (17) and (28).

$$(29)\quad E(y_t|I_{t-1})^f = E(y_t|I_{t-1})^* = E(y_t|I_{t-1})^{**} = \beta_2 y_{t-1}$$

The conditional variances, however, are different.[5/]

$$(30a)\quad Var(y_t|I_{t-1})^f = \left(\frac{\Pi_1[1+\alpha_2(1-\beta_2)] + \alpha_1\alpha_2\beta_2 - \alpha_1\beta_1(1+\alpha_2)}{\Pi_1[1+\alpha_2(1-\beta_2)] + \alpha_1\alpha_2\beta_2}\right)^2 \sigma_y^2$$

$$+ \left(\frac{\beta_1[1+\alpha_2(1-\beta_2)]}{\Pi_1[1+\alpha_2(1-\beta_2)] + \alpha_1\alpha_2\beta_2}\right)^2 \sigma_m^2$$

$$(30b)\quad Var(y_t|I_{t-1})^* = \sigma_y^2$$

$$(30c)\quad Var(y_t|I_{t-1})^{**} = 0$$

The next section of the paper shows that the existence of a very powerful stabilization role for monetary policy is quite consistent with a failure of money to Granger-cause output. For reasons of space I shall only consider the feedback rule (19) which keeps output at its *ex post* natural level and the associated output equation (17).

3. Granger-causality between money and output

The two reduced form time series processes for output and money are reproduced here for convenience.

$$(17)\quad y_t = \beta_2 y_{t-1} + u_t^y$$

$$(19)\quad m_t = \frac{\alpha_1(1+\alpha_2)^3}{\alpha_2^2[1+\alpha_2(1-\beta_2]} u^y_{t-2} + \left(\frac{1+\alpha_2}{\alpha_2}\right)^2 u^m_{t-2}$$

According to standard terminology, money fails to Granger-cause output in this bivariate, linear Gaussian setting if in a least squares regression of output on its own past values and on past values of the money supply, the regression coefficients on past values of the money supply are all equal to zero. To permit consideration of the more general definition of Granger-causality proposed e.g. in Granger [1980], the causality concept just referred to will be called causality in mean.

For any variable x_t, let $X^t \equiv \{x_s , s < t\}$.

Definition 1 m_t is said to Granger-cause y_t in mean if

$$E(y_t|Y^t, M^t) \not\equiv E(y_t|Y^t)$$

m_t fails to Granger-cause y_t in mean if

$$E(y_t|Y^t, M^t) \equiv E(y_t|Y^t).$$ [6/]

Clearly, money fails to Granger-cause output in mean, as

$$(31a)\quad E(y_t|Y^t) = E(y_t|y_{t-1}) = \beta_2 y_{t-1}$$

and

$$(31b)\quad E(y_t|Y^t, M^t) = E(y_t|y_{t-1}) = \beta_2 y_{t-1}$$

Output does Granger-cause money in mean as

(32a) $E(m_t|M^t) = 0$

and

(32b) $$E(m_t|M^t,Y^t) = \frac{\alpha_1(1+\alpha_2)^3}{\alpha_2^2[1+\alpha_2(1-\beta_2)]}(y_{t-2} - \beta_2 y_{t-3}) \quad .$$

Therefore $E(m_t|M^t,Y^t) \not\equiv E(m_t|M^t)$.

A much stronger form of Granger-causality refers to the entire conditional distribution of random variables instead of merely their conditional means. In the context of our bivariate model the following definition applies. For any variable x let $F(x_t|I_{t-1})$ denote the conditional distribution function of x_t given I_{t-1}.

<u>Definition 2</u> m_t is said to Granger-cause y_t if

$$F(y_t|Y^t,M^t) \not\equiv F(y_t|Y^t)$$

m_t fails to Granger-cause y_t if

$$F(y_t|Y^t,M^t) \equiv F(y_t|Y^t) \quad .$$ 7/

It is obvious from (17) and (19) that money fails to Granger-cause output in this much stricter sense as well. The distribution function of y_t (and m_t) is fully described by its first two moments. Note that

(33) $$E\left[\left(y_t-E(y_t|Y^t)\right)^2\middle|Y^t\right] \equiv E\left[\left(y_t-E(y_t|Y^t,M^t)\right)^2\middle|Y^t,M^t\right] = \sigma_y^2$$

Also:

$$\text{(34a)} \left[E\left(\left(m_t - E(m_t|M^t)\right)^2 \middle| M^t\right)\right] = \frac{\alpha_1^2(1+\alpha_2)^6}{\alpha_2^4[1+\alpha_2(1-\beta_2)]^2}\sigma_y^2 + \left(\frac{1+\alpha_2}{\alpha_2}\right)^4 \sigma_m^2$$

$$\text{(34b)} \; E\left[\left(m_t - E(m_t|M^t,Y^t)\right)^2 \middle| M^t,Y^t\right] = \left(\frac{1+\alpha_2}{\alpha_2}\right)^4 \sigma_m^2$$

Therefore

$$\text{(35)} \left[E\left(\left(m_t - E(m_t|M^t)\right)^2 \middle| M^t\right)\right] \neq E\left[\left(m_t - E(m_t|M^t,Y^t)\right)^2 \middle| M^t,Y^t\right]$$

Equation (33) shows that money also fails to Granger-cause output in terms of the second moment of output while (35) states that output Granger-causes money also in terms of the second moment of money. 8/

The failure of money to Granger-cause output (and Granger-causation of money by output) is quite consistent with the powerful stabilization potential of money established in the previous section.

4. Granger-causality and "automatic stabilizers"

Granger-causality tests also convey no information about the presence or absence of a role for "automatic stabilizers", that is instantaneous feedback rules relating the current value of the policy instrument to part or all of the current information set. The discussion of automatic stabilizers is usually restricted to fiscal policy: "features of the tax structure that make tax liabilities respond automatically to current economic conditions" (McCallum and Whitaker [1979, p.172]). McCallum and Whitaker [1979] rationalize the stabilizing potential of automatic stabilizers through the *decentralized* setting of the control variables that they permit. Aggregative information on GDP and the general price level is assumed to be available only with a lag. Transfer payments such an unemployment benefits are, however, paid out according to fixed rules on a decentralized basis, when claims are made by the individual unemployed workers. This permits an immediate response to changing economic conditions without any need to wait for aggregate output and unemployment data to become available. There are many problems associated with this interpretation. One is that with efficient capital markets the *timing* of the unemployment benefits would be of no concern. Any rule for delayed payments of the benefits which leaves the real present value of these benefits unchanged would have the same effect on behaviour. Unspecified capital market imperfections must therefore play a role if automatic stabilizers have a stabilizing potential that is not present with feedback rules that make current policy instrument values functions only of lagged information. As a satisfactory treatment of these issues would require a full paper in its own right, I shall say no more about them here.

If automatic decentralized fiscal stabilizers exist, so do monetary stabilizers. Those in charge of the local unemployment registers could be instructed to perform an open market purchase of government bonds of a given amount for every worker joining the unemployment register, and an open market sale for every notified vacancy.[9/]

Consider the model of equations (36), (37) and (38). As all expectations of future endogenous variables are conditioned on the same information set, I_{t-1}, there is no stabilizing role for monetary feedback rules relating m_t to past values of m_t, p_t or y_t or to past values of the random disturbances. Equation (38) is the instaneous monetary feedback rule or automatic stabilizer.

$$(36) \quad m_t - p_t = \alpha_1 y_t - \alpha_2 E\left((p_{t+1}-p_t) \mid I_{t-1}\right) + u_t^m$$

$$(37) \quad y_t = \beta_1\left(p_t - E(p_t \mid I_{t-1})\right) + \beta_2 y_{t-1} + u_t^y$$

$$(38) \quad m_t = \mu y_t .$$

The rational expectations solution for output is:

$$(39) \quad y_t = \beta_2 y_{t-1} + \frac{1}{1+(\alpha_1-\mu)\beta_1} u_t^y - \frac{\beta_1}{1+(\alpha_1-\mu)\beta_1} u_t^m$$

It is clear from (39) that while the conditional mean of output is independent of the value of μ, the conditional variance of output is a function of μ. Also, from (38) and (39) money fails to Granger-cause output either "in mean" or "in variance". In this case, of course, output also fails to Granger-cause money, as m_t is merely a linear transformation of y_t.

5. Granger-causality and stabilization policy with a Fischer-Phelps-Taylor-type supply function.

Fischer [1977], Phelps and Taylor [1977] and Taylor [1980] have demonstrated the existence of a potential stabilization rule for monetary feedback rules in models in which money wages or prices must be set more than one period in advance. Such predetermined money wages or prices reflect all the information available at the time the contracts are negotiated. They cannot, however, respond to new information that may become available between the contract date and the period for which wages or prices are set. Deterministic monetary feedback rules that permit the money stock to respond to new information to which private agents that are "locked into" pre-existing nominal contracts cannot respond, can now affect the behaviour of the real economy. The microeconomic rationality of such "open-loop" nominal contracts is open to question (see e.g. Barro [1977]) but will not be considered here. The only aim of this section is to show that failure of money to Granger-cause output is consistent with a potential stabilization role for money in a model in the spirit of Fischer, Phelps and Taylor.

The model is given in equations (40) and (41).

$$(40) \qquad m_t - p_t = y_t + u_t^m$$

$$(41) \qquad y_t = \beta_1\left[p_t - E(p_t|I_{t-1})\right] + \beta_1'\left[p_t - E(p_t|I_{t-2})\right] + \beta_2 y_{t-1} + u_t^y$$

Equation (40) is a very much simplified portfolio balance condition. An output equation such as (41) could arise, e.g. if some of the money wage contracts for period t are set in period t-1 while the rest are set in period t-2. The information set I_t contains, as before, all current and past values of m_t, p_t and y_t and therefore also the current and past values of u_t^m and u_t^y.

Straightforward algebra yields the result that

$$(42a) \qquad p_t - E(p_t|I_{t-1}) = \frac{1}{\Omega}\left[m_t - E(m_t|I_{t-1})\right] - \frac{u_t^m}{\Omega} - \frac{u_t^y}{\Omega}$$

and

$$(42b) \qquad p_t - E(p_t|I_{t-2}) = \frac{1}{\Omega}\left[m_t - E(m_t|I_{t-2})\right] + \frac{\beta_2(\beta_1+\beta_1')}{\Omega(1+\beta_1')}\left[m_{t-1} - E(m_{t-1}|I_{t-2})\right]$$

$$+ \frac{\beta_1}{\Omega(1+\beta_1')}\left[E(m_t|I_{t-1}) - E(m_t|I_{t-2})\right]$$

$$- \frac{u_t^m}{\Omega} - \frac{u_t^y}{\Omega}$$

$$+ \frac{\beta_2(\beta_1+\beta_1')}{\Omega(1+\beta_1')} u_{t-1}^m - \frac{\beta_2}{\Omega(1+\beta_1')} u_{t-1}^y \, .$$

(42c) $\Omega = 1 + \beta_1 + \beta_1'$

Therefore,

(43) $$y_t = \beta_2 y_{t-1} + \frac{\beta_1}{\Omega}\left(m_t - E(m_t|I_{t-1})\right) + \frac{\beta_1'}{\Omega}\left(m_t - E(m_t|I_{t-2})\right)$$

$$- \frac{\beta_1'\beta_2(\beta_1+\beta_1')}{\Omega(1+\beta_1')}\left(m_{t-1} - E(m_{t-1}|I_{t-2})\right) + \frac{\beta_1'\beta_1}{\Omega(1+\beta_1')}\left[E(m_t|I_{t-1}) - E(m_t|I_{t-2})\right]$$

$$- \frac{(\beta_1+\beta_1')}{\Omega}u_t^m + \frac{1}{\Omega}u_t^y + \frac{\beta_1'\beta_2(\beta_1+\beta_1')}{\Omega(1+\beta_1')}u_{t-1}^m - \frac{\beta_1'\beta_2}{\Omega(1+\beta_1')}u_{t-1}^y \quad .$$

Given any non-stochastic open-loop rule for the money supply, $m_t = E(m_t|I_{t-1}) = E(m_t|I_{t-2})$ for any t. Under such a rule the behaviour of output is governed by:

(44) $$y_t = \beta_2 y_{t-1} - \frac{(\beta_1+\beta_1')}{\Omega}u_t^m + \frac{1}{\Omega}u_t^y + \frac{\beta_1'\beta_2(\beta_1+\beta_1')}{\Omega(1+\beta_1')}u_{t-1}^m - \frac{\beta_1'\beta_2}{\Omega(1+\beta_1')}u_{t-1}^y$$

From equation (43) it is clear that only monetary feedback rules that make m_t a function of I_t or of I_{t-1} will affect the density function of y_t. This is because the earliest expectation affecting y_t in (41), given y_{t-1}, is conditioned on I_{t-2}. More generally, in models such as the one of (40) and (41) in which y_t is not a function of expectations of endogenous variables in periods beyond t, the following proposition holds. If I_{t-k}, $k > 0$ is the earliest information set conditioning expectations that affect y_t only feedback rules relating m_t to I_{t-k+j}, $0 < j < k$, will affect the density function of y_t. Since instantaneous feedback rules have already been considered, consider the feedback rule (45)

(45) $$m_t = \mu_1 u_{t-1}^y + \mu_2 u_{t-1}^m .$$

With this rule, $m_t = E(m_t|I_{t-1})$ for any t and $m_t - E(m_t|I_{t-2}) = \mu_1 u_{t-1}^y + \mu_2 u_{t-1}^m$.

With the feedback rule (45) the behaviour of output is governed by:

$$(46) \quad y_t = \beta_2 y_{t-1} - \frac{(\beta_1+\beta_1')}{\Omega} u_t^m + \frac{1}{\Omega} u_t^y + \frac{\beta_1'}{1+\beta_1'}\left(\mu_1 - \frac{\beta_2}{\Omega}\right) u_{t-1}^y + \frac{\beta_1'}{1+\beta_1'}\left(\mu_2 + \frac{\beta_2(\beta_1+\beta_1')}{\Omega}\right) u_{t-1}^m$$

It is clear from (46) that the density frunction of y_t is not independent of the values of μ_1 and μ_2. Consider e.g. the policy that eliminates the last two terms of the R.H.S. of (46)

$$(47) \quad \mu_1 = \frac{\beta_2}{\Omega}$$

$$\mu_2 = \frac{-\beta_2(\beta_1+\beta_1')}{\Omega}.$$

The behaviour of output is then given by (48)

$$(48) \quad y_t = \beta_2 y_{t-1} - \frac{(\beta_1+\beta_1')}{\Omega} u_t^m + \frac{1}{\Omega} u_t^y$$

The money supply process is:

$$(49) \quad m_t = \frac{\beta_2}{\Omega} u_{t-1}^y - \frac{\beta_2(\beta_1+\beta_1')}{\Omega} u_{t-1}^m.$$

Money fails to Granger-cause output "in mean" and "in variance".

$$(50a) \quad E(y_t|Y^t) = \beta_2 y_{t-1} = E(y_t|Y^t, M^t)$$

$$(50b) \quad E\left[\left(y_t - E(y_t|Y^t)\right)^2 \Big| Y^t\right] = \left(\frac{\beta_1+\beta_1'}{\Omega}\right)^2 \sigma_m^2 + \frac{1}{\Omega^2} \sigma_y^2 = E\left[\left(y_t - E(y_t|Y^t, M^t)\right)^2 \Big| Y^t, M^t\right]$$

Output Granger-causes money "in mean" and "in variance".

(51a) $$E(m_t|M^t) = 0 \neq E(m_t|M^t, Y^t) = m_t$$ 10/

(51b) $$E\left[\left(m_t - E(m_t|M^t)\right)^2 \Big| M^t\right] = \left(\frac{\beta_2}{\Omega}\right)^2 \sigma_y^2 + \left(\frac{\beta_2(\beta_1+\beta_1')}{\Omega}\right)^2 \sigma_m^2$$

$$\neq E\left[\left(m_t - E(m_t|M^t, Y^t)\right)^2 \Big| M^t, Y^t\right] = 0$$

Thus, in models with long-term nominal contracts in the spirit of Fischer, Phelps and Taylor, the existence of a potential stabilization role for monetary feedback rules is quite consistent with a failure of money to Granger-cause real variables.

6. Granger-causality and allocative policy

Once we no longer restrict the analysis to the consideration of pure stabilization policy instruments, invariance of the conditional means of real variables with respect to policy instruments is no longer implied by failure of the policy instruments to Granger-cause the real variables. Consider the model in equations (52) and (53). In (52) output depends on lagged output and on the past, current and expected future values of a fiscal policy instrument f. This could be the income tax rate, the payroll tax rate, the profits tax rate or any other non-lump-sum tax. For expositional simplicity the influence on current output y_t of anticipated future policy instrument values is restricted to policy anticipated for one period into the future. Equation (53) is the policy feedback rule.

(52) $y_t = \alpha_1 y_{t-1} + \alpha_2 f_t + \alpha_3 E(f_{t+1}|I_t) + \alpha_4 f_{t-1} + u_t$

(53) $f_t = \beta y_{t-2}$

u_t is an independent, identically distributed disturbance term. The information set I_t contains all current and lagged values of y_t and f_t and the correct structure of the model.

Using (53) to eliminate the expectations in (52) we obtain:

(54) $y_t = (\alpha_1 + \alpha_3\beta) y_{t-1} + \alpha_2\beta y_{t-2} + \alpha_4\beta y_{t-3} + u_t$

f_t fails to Granger-cause y_t "in mean" as [11/]

(55) $E(y_t|Y^t) = (\alpha_1 + \alpha_3\beta) y_{t-1} + \alpha_2\beta y_{t-2} + \alpha_4\beta y_{t-3} = E(y_t|Y^t,F^t).$

From (54) it is clear that the conditional mean of output is a function of β, the policy feedback parameter:

(55) $E(y_t|I_{t-1}) = (\alpha_1 + \alpha_3\beta) y_{t-1} + \alpha_2\beta y_{t-2} + \alpha_4\beta y_{t-3}$. [12/]

7. Conclusion

The failure of Granger-causality tests to reveal the stabilizing potential of deterministic monetary feedback rules can in part be attributed to one of the axioms underlying these tests. According to Granger [1980, p.330] "The past and present may cause the future but the future cannot cause the past". As regards the channel through which monetary policy operates in the model of Sections 2 and 3, the future, or at any rate the anticipation of the future, does "cause" or influence the past. Current revisions in the anticipations of future policy instrument values influence the current behaviour of the real economy.[13/] Current output is a function not of current and past money supplies but of (revisions in) expectations of future money supplies. These forecast revisions can be influenced by known feedback rules. In Section 4, failure of money to Granger-cause output did not preclude a stabilizing role for instantaneous monetary feedback rules or automatic stabilizers. In the multi-period nominal contracts model of Section 5, monetary feedback rules affected the density function of real output even though money did not Granger-cause output. If we do not restrict outselves to the consideration of pure stabilization policy instruments, the conditional means of the real variables can be functions of the parameters of the policy feedback rule, even if the policy instruments do not Granger-cause the real variables. This is true regardless of whether it is current, lagged or anticipated future instrument values that affect real behaviour.

Granger-causality tests, especially their multivariate, simultaneous-equations versions, are important tools for preliminary data analysis and for diagnostic tests of specification and data-coherence of structural models. Sargent has demonstrated (Sargent [1976, p.222]) that it is possible for stabilization policy instruments to Granger-cause real variables without this implying any role for systematic stabilization policy. This paper warns against the Type II error that complements the Type I error Sargent cautioned against. Failure of stabilization instruments to Granger-cause real variables is not sufficient to rule out a role for systematic stabilization policy. Granger-causality tests are tests of "incremental predictive content" (Schwert [1979, p.82]). They cannot confirm or deny a role for stabilization policy.

FOOTNOTES

1/ One set of variables, x, is said to Granger-cause another set, y, if adding past values of x in a regression equation for predicting y that already includes all past values of y as regressors, improves the predictive power of the equation in the sense that it reduces the mean squared forecast error. (e.g. Hsaio [1979]). A more formal definition is given in Section 3.

2/ An example of Sargent [1976, p. 222] suffices to make this point. Let V_t be the unemployment rate and m_t the logarithm of the nominal money stock.

$$V_t = \lambda V_{t-1} + \beta_0\left(m_t - E(m_t|I_{t-1})\right) + \beta_1\left(m_{t-1} - E(m_{t-1}|I_{t-2})\right) + u_t$$

$$m_t = \sum_{i=1}^{n} \delta_i m_{t-i} + \varepsilon_t .$$

ε_t and u_t are Gaussian random disturbances. E is the expectation operator and I_t the information set in period t conditioning expectations formed in period t. It is easily seen that

$$E(V_t|V_{t-1}, V_{t-2}, \ldots ; m_{t-1}, m_{t-2}, \ldots)$$

$$= \lambda V_{t-1} + \beta(m_{t-1} - \sum_{i=1}^{n} \delta_i m_{t-1-i}).$$

Therefore, m helps predict or Granger-causes V. However, deterministic feedback rules making m_t a linear function of I_{t-i}, $i > 0$, cannot affect the density function of V_t. Note that if it is possible to relate m_t to I_t, such instantaneous feedback rules will affect the density function of V_t, (see Section 4).

3/ Sims does not endorse the view he refers to.

4/ and a finite bound on $\lim_{N\to\infty} E(p_{t+1+N}|I_t)$.

5/ The conditional variances equal the unconditional variances in this model.

6/ Granger [1980], p.337 .

7/ Granger [1980], pp.336-337 .

8/ Note that money and the price level also fail to jointly Granger-cause output, either "in mean" or "in variance". This is clear from inspection of (17), (18) and (26).

9/ I owe this argument to John Flemming.

10/ Note that $y_{t-1} - \beta_2 y_{t-2} = \frac{1}{\Omega} u^y_{t-1} - \left(\frac{\beta_1+\beta_1'}{\Omega}\right) u^m_{t-1}$ and that

$$m_t = \beta_2 \left[\frac{1}{\Omega} u^y_{t-1} - \left(\frac{\beta_1+\beta_1'}{\Omega}\right) u^m_{t-1}\right]$$

11/ It is easily checked that y_t Granger-causes f_t "in mean", that f_t fails to Granger-cause y_t "in variance" and that y_t Granger-causes f_t "in variance".

12/ The same conclusion holds even if only the past value of f affects y in (52), i.e. if $\alpha_2 = \alpha_3 = 0$.

13/ Optimal policy design is therefore likely to encounter the time-inconsistency problem. See Kydland and Prescott [1977], Buiter [1980 b] and Buiter and Eaton [1980 c].

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