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THE SUPERIORITY OF CONTINGENT RULES OVER FIXED RULES IN MODELS WITH RATIONAL EXPECTATIONS

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ABSTRACT

The paper investigates the robustness of the proposition that in stochastic models contingent or feedback rules dominate fixed or open-loop rules. Four arguments in favour of fixed rules are considered. 1) The presence of an incompetent or malevolent policy maker. 2) A trade-off between flexibility and simplicity or credibility. 3) The New Classical proposition that only unanticipated (stabilization) policy has real effects. 4) The "time-inconsistency" of optimal plans in non-causal models, that is models in which the current state of the economy depends on expectations of future states. The main conclusion is that the "rational expectations revolution", represented by arguments (3) and (4) does not affect the potential superiority of (time-inconsistent) closed-loop policies over (time-inconsistent) open-loop policies. The case against conditionality in the design of policy must therefore rest on argument (1) or (2) which predate the New Classical Macroeconomics.

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The Superiority of Contingent Rules over Fixed Rules in Models with Rational Expectations *

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I Introduction

This paper analyses an old controversy in macroeconomic theory and policy: "rules versus discretion" or, more accurately, *fixed* rules (rules without feedback or open-loop rules) versus *flexible* rules (contingent rules, conditional rules, rules with feedback or closed-loop rules). With open-loop policies the actual current and future values of the policy instruments are specified at the beginning of the policy maker's planning period. The time paths of the policy instruments are therefore functions only of the information available at the beginning of the planning period; they are to be implemented without regard to any new information that may accrue as time passes. Milton Friedman's advocacy of a fixed growth rate for some monetary aggregate is probably the best-known example of a (very simple) open-loop rule.[1/] Formally, let x_t denote the value of the instrument vector in period t, I_t the information set available to the policy maker at the beginning of period t, when x_t is chosen. $t = 1$ is the beginning of the planning period and $t = T > 1$ the end. A plan or rule consists of a choice, at $t = 1$, of a set of functions f_t, $t = 1, \ldots, T$ or $\{f_t\}$ relating the x_t, $t = 1, \ldots, T$ to some information set. Open-loop policies or fixed rules are defined by:

(I.1) $$x_t = f_t(I_1) \qquad t = 1, \ldots, T.$$

Contingent policies or flexible rules specify the values of the policy variables in current and future periods as functions g_t, $t = 1, \ldots, T$, or $\{g_t\}$, known at $t = 1$, of the information that will be available when these instrument values will actually have to be assigned (i.e. I_t for x_t),[2/] but may not yet be available at the beginning of the planning period when the rule $\{g_t\}$ is chosen. Thus future policy instrument values are known functions of observations yet to be made. In an uncertain world, this means that instrument values in periods $\tau > 1$ can respond to the observation of realizations of random variables between periods 1 and τ. Closed-loop policies or contingent rules are therefore defined by:

(I.2) $$x_t = g_t(I_t) \qquad t = 1, \ldots T.$$

Note again that the g_t are chosen at $t = 1$ for the entire planning period. There is no serious disagreement that policy should be determined by rules, i.e. by functions known at $t = 1$, rather than by arbitrary, unpredictable actions "on the spur of the moment". There is no consensus on the desirability of fixed rules *vis-á-vis* contingent rules.

The standard theory of optimization in stochastic dynamic models appears to yield the unambiguous conclusion that in an uncertain world the optimal contingent rule will always dominate the optimal fixed rule. This is most easily demonstrated using the familiar linear-quadratic stochastic dynamic programming problem studied e.g. in Chow [1975]. A quadratic loss function (I.3) is minimised subject to the constraints of a stochastic linear model (I.4).

(I.3) $$\min_{\{x_t\}} E_1\left[\tfrac{1}{2}\sum_{t=1}^{T}(y_t - a_t)'\,K_t(y_t - a_t)\right]$$ subject to

(I.4) $$y_t = A_t y_{t-1} + C_t x_t + b_t + u_t \quad 3/$$

$$y_o = \bar{y}_o$$

y_t is the state vector, $\bar{y}_o$ the initial state. x_t is a vector of control instruments, b_t is a vector of exogenous variables. u_t is a vector of stochastic disturbances which has a zero mean and a constant contemporaneous variance-covariance matrix and is serially uncorrelated. E_1 is the expectation operator, conditional on the information available at the beginning of period 1, a_t is a vector of target values of the state vector and K_t a non-negative definite weighting matrix penalizing deviations of the state variables from their target values. a_t, K_t, A_t, C_t and b_t are known vectors or matrices.

If the information at the beginning of a period, τ, includes the model (the a_t, K_t, A_t, C_t and b_t matrices for $t = 1, \ldots, T$) and the past values of y_t and x_t (and therefore of u_t) but not the current, period τ, value of y_t or u_t, the optimal closed-loop policy rule takes the following time-varying linear feedback form: (see Chow [1975]).

(I.5a) $$x_t = G_t y_{t-1} + g_t$$

(I.5b) $$G_t = (C_t' H_t C_t)^{-1} C_t' H_t A_t$$

(I.5c) $$g_t = - (C_t' H_t C_t)^{-1} C_t' (H_t b_t - h_t)$$

(I.5d) $$H_{t-1} = K_{t-1} + A_t' H_t (A_t + C_t G_t) \qquad t = 1, \ldots, T - 1$$

(I.5e) $$h_{t-1} = K_{t-1} a_{t-1} - A_t' (H_t (b_t + C_t g_t) - h_t) \qquad t = 1, \ldots, T - 1$$

(I.5f) $$H_T = K_T$$

(I.5g) $$h_T = K_T a_T$$

For future reference a short digression on the standard solution technique for this class of stochastic dynamic models is required. The optimal feedback policy is derived using stochastic dynamic programming. According to Bellman's Principle of Optimality, "An optimal policy has the property that, whatever the initial state and decision (i.e. control) are, the remaining decisions must constitute an optimal policy with regard to the state resulting from the first decision" (Bellman [1957]). This means that the optimal instrument choice for period t, x_t^*, $t = 1, \ldots, T$, can be obtained as the solution of the one-period optimization problem:

(I.6) $$\min_{x_t} W_t = E_t\left[\tfrac{1}{2}(y_t - a_t)' K_t (y_t - a_t)\right] + W^*_{t+1}$$

where $W^*_{t+1} = \min W_{t+1}$

subject to (I.4).

Thus the problem for the last period, T, is solved first, and the best policy x_T is choosen for the last period, contingent on any initial condition y_{T-1}. Next the two-period problem is solved for the last two periods by choosing the optimal x_{T-1}, contingent on the initial condition y_{T-2} and allowing for the fact that next period x_T will be chosen optimally, given y_{T-1}. Next the three period problem for the last three periods is solved etc. It should be noted that the T-period problem is solved backward in time, one step at a time, thus taking advantage of the 'time-structure' of the model. At each step, only one unknown policy vector x_t is determined as a function of the initial state y_{t-1}. The policy instruments in period t are a known (as of t = 1) function of all the information available in period t, represented in this case by y_{t-1}. The value of y_{t-1} is partly determined by the random disturbance u_{t-1}, which is observed (or inferred) when x_t is chosen but not in any earlier period. The optimal closed-loop policy which permits a flexible response to new information as it becomes available, therefore dominates any open-loop policy: the expected loss under the optimal closed-loop policy is smaller than the expected loss under the optimal open-loop policy. (Chow [1975]). This result appeals to commonsense: it should always be possible to do better if one can respond to unforeseen events and other new information than if such a response is ruled out. Only in the uninteresting special case of a model without uncertainty will the optimal closed-loop policy and the optimal open-loop policy be equivalent, i.e. generate equal values for the loss function.

This proposition that the optimal closed-loop rule dominates any fixed rule, including the optimal fixed rule, is robust. It holds for non-linear models and for more general objective functions. The model parameters A_t, C_t and b_t may be random variables. (See Chow [1975]). Generalizations of (I.5a) - (I.5g) exist for the case in which y_{t-1} is not observable at the beginning of period t when x_t is chosen, due to measurement lags, and for the case in which y_t is never measured perfectly, no matter how often the estimate is revised.4/ The superiority of the optimal closed-loop rule over the optimal open-loop rule also holds when it takes time to decide upon and physically realize a control action and when not every policy instrument can be adjusted each period - the case of "intermittent" controls (Deissenberg [1979a]). Finally, the dominance of the optimal flexible rule carries over to the case in which more information is available when x_t is chosen. The solution given in (I.5a) - (I.5g) assumed that neither y_t nor u_t had been observed when x_t was set. If instead a possibly imprecise and partial observation ζ_t on y_t is available at time t when x_t is chosen, in addition to full and accurate information on lagged values of y_t, (I.5a) - (I.5g) generalizes to an optimal, time-varying linear feedback rule that makes x_t a function not only of y_{t-1} but also of ζ_t.5/

The proposition that optimal contingent rules are superior to optimal fixed rules is analytically robust and appeals to commonsense: contingent rules permit new information to be taken into account when the actual course of the policy instruments is selected. Fixed rules do not permit any response to new information -- the policy maker is "locked in". In view of this happy marriage of analytical rigour and intuition, how can respected economists argue in favour of fixed rules over flexible rules? Four grounds for such a view are analysed in the next four sections of the paper. The first is Friedman's "long and variable lags" argument. It predates the New Classical Macroeconomics. The second concerns a possible trade-off between flexibility and simplicity in the design of policy rules. The last two are based on quite distinct aspects of the rational expectations or New Classical Macroeconomics revolution. One derives from the assumption that only unanticipated stabilization policy will have real effects. The second is based on the "inconsistency of optimal plans", the proposition due to Kydland and Prescott [1977] that, even when anticipated policies have real effects, feedback rules derived from dynamic programming (called "consistent" policies by Kydland and Prescott) will be suboptimal in models in which the current state is a function of rational expectations of future states.

II Long and variable lags and the not-so-competent or not-so-well-intentioned government.

Unlike the New Classical Macroeconomics School, Milton Friedman does not reject in principle the proposition that even anticipated monetary, fiscal and financial policies can have important real effects, in the short run and possibly even in the long run. However, these effects come with lags that are often long and always variable and uncertain.[6/] In such an uncertain environment, the derivation of the best contingent rule becomes a difficult task, even for a well-informed, competent and well-intentioned policy maker. By itself, uncertainty about the magnitude and timing of the response of target variables to instruments in no way affects the dominance of the optimal feedback rule over any fixed rule. Random A_t, C_t and b_t matrices in (L4) increase the magnitude of the minimum expected value of the loss function in (L3) relative to the case where there is no uncertainty about the parameters of the model, but the principle that it is always optimal to make full use of all available information remains valid.

Friedman's preference for fixed rules over flexible rules can therefore not be derived from uncertainty about model specification *per se*. It requires the further assumption that, unconstrained by fixed rules, the government either pursues the wrong objectives or pursues the right objectives in the wrong manner, because of inferior information or incompetent use of available information in the design of feedback rules. It is important to note that it is only the *optimal* contingent rule that is necessarily superior to any fixed rule, given an agreed upon objective function or loss function, not <u>any</u> contingent rule.

Even if the public and the private sector have the same objective functions, there certainly exist contingent rules that are a lot worse than any fixed rule. Misdirected "stabilization policy" can be destabilizing, as was first formally demonstrated by Phillips [1957, 1964]. The converse of the proposition is that if monetary, fiscal and financial policies have important effects on the real economy and if the magnitude and timing of these effects is uncertain, then the adoption of fixed rules (and even of the optimal fixed rule) may lead to very unfavourable outcomes, quite possibly worse than would result from the adoption of some less-than-ideal, sub-optimal flexible rule. To reach Friedman's conclusion that a fixed monetary rule should be adopted, it is necessary to assume not only that the government would not adopt the optimal feedback rule but that it would choose from among all sub-optimal feedback rules, one that would be dominated by a simple fixed rule.

Instead of the inefficient pursuit of the right objectives, the efficient pursuit of the wrong objectives by the government could be the reason for advocating fixed rules. If short-run political and electoral expediency takes precedence over the pursuit of economic welfare, it may be preferable to constrain the policy options of the authorities by committing them to simple fixed rules, if necessary by law or even, in the U.S.A., by constitutional amendment.

To summarize, uncertainty aboutthe timing and magnitude of the response of the economy to policy changes does not negate the validity of the general proposition that the optimal contingent rule dominates the optimal fixed rule. Whether the optimal contingent rule will be adopted does of course depend on the ability and integrity of those responsible for the conduct of economic policy. Friedman's advocacy of a fixed rule for the money supply cannot be derived from "long and variable lags". Instead it should be viewed as the expression of a very practical concern about the wisdom of leaving powerful instruments with uncertain effects in the hands of persons or agencies with limited ability and sometimes dubious motives. Even if this concern is valid, a fixed monetary rule may well be destabilizing in a world that is subject to a variety of internal and external disturbances. If anticipated money matters for the real economy, a fixed monetary rule is not necessarily a safe rule. Such a rule would make sense only if there are no significant sources of disturbances elsewhere in the system and if the exogenous variables follow smooth growth paths.

III The trade-off between flexibility and simplicity

The optimal contingent rule stated in (I.5a) to (I.5g) shows that the values of the policy instruments in period t are a complicated function of the entire state vector. If there are constraints on the ability of the private sector to understand and predict government behaviour, the complex contingent rule that emerges as optimal when such constraints are ignored may well turn out to be far from optimal in practice. The predictability of government behaviour may be impaired and the credibility of its policies undermined (see e.g. Minford [1980]). Against this, it should be noted that very simple fixed rules may well be subject to equally severe credibility problems. There are likely to be contingencies under which any fixed rule is bound to be discarded. E.g. an unanticipated doubling of world oil prices is likely to be associated with some relaxation of the money supply target. If the direction and magnitude of the policy response to such an unanticipated shock have not been announced in advance in the form of a conditional rule, the credibility of the open-loop policy is undermined and uncertainty about future policy enhanced (see Artis [1980] and Buiter [1980d]). It is possible, in principle, to strike a balance between conditionality and simplicity by selecting the optimal contingent rule among a restricted class of simple feedback rules. Since every fixed rule is always a special case of any contingent rule, however simple, it will be possible to identify the circumstances, if any, under which the optimal open-loop rule will be no worse than the restricted optimal contingent rule. Unless any form of conditionality, however simple, introduces policy instrument uncertainty that is not present when fixed rules are adopted, the optimal open-loop rule can never dominate even a very restricted optimal contingent rule.

IV Only unanticipated stabilization policy has real effects

The second argument in favour of fixed rules or, more generally in favour of simple rules is based on the proposition that stabilization policy is irrelevant for the behaviour of the real economy to the extent that it is anticipated or perceived by private agents. This view can be illustrated with the "semi-reduced form model" of equation (IV.1), made familiar through the work of Barro [1977, 1978]. y_t denotes a vector of real economic variables, x_t a vector of stabilization policy instruments, z_t a vector of exogenous and predetermined variables possibly including other non-stabilization policy instruments and u_t a white noise disturbance vector. Equations such as (IV.1) are called "semi-reduced forms" because instrument expectations which are potentially endogenous still appear on the right-hand side. $\hat{x}_{t_1|t_o}$ denotes the value of x in period t_1 as anticipated in period t_o .

$$\text{(IV.1)} \quad y_t = A_1 z_t + \sum_{i=o}^{T_1} B_i (x_{t-i} - \hat{x}_{t-i|t-i}) + \sum_{i=o}^{T_1} C_i x_{t-i} + u_t$$

The effect of an anticipated or more precisely, contemporaneously perceived increase in x_{t-i} on y_t is given by

$$\text{(IV.2a)} \quad \frac{\partial y_t}{\partial x_{t-i}} + \frac{\partial y_t}{\partial \hat{x}_{t-i|t-i}} = C_i$$

The effect of an unanticipated or contemporaneously unperceived increase in x_{t-i} on y_t is given by

(IV.2b) $$\frac{\partial y_t}{\partial x_{t-i}} = B_i + C_i$$

The New Classical Macroeconomics School asserts that for some set of stabilization policy instruments, x_t , all the C_i matrices are zero: anticipated stabilization policy has no effect on the joint probability density functions of real variables. If this view is correct, the government can influence real economic activity only by making the actual behaviour of its stabilization instruments different from what the private sector anticipates or infers them to be, i.e. only by "fooling" the private sector. Since changes in real economic behaviour brought about only through faulty perceptions of the actual policies pursued by the authorities are unlikely to be welfare-increasing,[7] the implications of the restriction that $C_i = 0$ for the conduct of policy appear self-evident: the only contribution that government can make to minimizing variations in real economic activity is to minimize uncertainty about its own behaviour, i.e. to maximize the predictability of its own actions. Any known rule, fixed or contingent, will be "neutral". The demands made on the information gathering and processing resources of the private sector and on private sector forecasting and inference ability are likely to be minimized if the simplest possible fixed rule is adopted: a simple fixed rule is more easily incorporated in private information sets than a complex contingent rule. Even in a model like (IV.1), deterministic monetary policy rules can have real effects if the authorities have an informational advantage over the private sector. As this issue is treated clearly elsewhere (e.g. Barro [1976]) no further attention need be paid to it here.

The conclusion that if only unanticipated policy affects real variables, known deterministic policy feedback rules are without real effects is not robust. There are two generalizations of (IV.1) for which known contingent policy rules are effective by influencing the monetary prediction or forecast errors. They are given below.

1) Expectations of policy instrument values in a given period conditioned at different dates and the speed of policy response

Assume for the sake of argument that in (IV.1), $C_i = 0$ for all i. If the policy forecast error term includes forecast errors for current and lagged x based on forecasts made currently or in the past, (say for forecast horizons $j = o, 1, \ldots, S_1$,) equation (IV.1) becomes

$$\text{(IV.1')} \qquad y_t = A_1 z_t + \sum_{i=o}^{T_1} \sum_{j=o}^{S_1} B_{ij}(x_{t-i} - \hat{x}_{t-i|t-i-j}) + u_t$$

If expectations are rational

$$\text{(IV.3)} \qquad \hat{x}_{t_1|t_o} = E(x_{t_1}|I_{t_o})$$

E is the mathematical expectation operator and I_τ the information set at $t = \tau$ conditioning the expectation.

The following proposition is now easily established.

Proposition 1. Provided at least some private actions affecting y_t depend on private forecasts of x_{t-i} that are based on earlier, and therefore less complete information than the information used by the policy authorities in setting x_{t-i}, known contingent rules will affect the probability density function of y_t even if $C_i = 0$ for all i.

This proposition is due to Fischer [1979] and to Phelps and Taylor [1977]. Note that both public and private agents can have the same *information set* in any given period (I_t in period t , I_{t-1} in period t-1, etc.). If however, the lag with which some private agents react to new information is longer than the lag with which the policy authorities can adjust at least one of their instruments, or if the authorities can write and enforce contingent forward contracts (the contingent policy rules) that the private sector either cannot duplicate or does not find in its perceived best interest to duplicate, then these known contingent policy rules will influence real outcomes. The crucial assumption is the existence of a difference in private and public *opportunity sets* (see Woglom [1979], Buiter [1980 a, c, e], McCallum and Whitaker [1979]).[8/] Multi-period private nominal wage or price contracts that are not made contingent on the information that will become available over the life of the contract but are a function only of the information at the initial contract date,[9/] combined with monetary policy rules that make the money supply in any given period a known function of the full information set available to public and private agents in that period, provide the best-known examples of deterministic monetary feedback rules with real effects (see Fischer [1977], Phelps and Taylor [1977], Taylor [1977, 1980], Buiter and Jewitt [1980]). A simple example that closely follows Fischer [1977] is given below.

(IV.4) $a_t = y_t$

(IV.5) $a_t = \alpha_1 y_t + \alpha_2(m_t - p_t) + u_t^a \qquad \alpha_1 , \alpha_2 > 0$

(IV.6) $w_t - p_t = -\beta \ell_t^d + u_t^\ell$ $\beta > 0$

(IV.7) $\ell_t^s = \gamma(w_t - p_t)$ $\gamma > 0$

(IV.8) $\ell_t = \ell_t^d$

(IV.9) $y_t = \delta \ell_t$ $1 > \delta > 0$

All variables are in logarithms. (IV.4) states that aggregate demand a equals aggregate supply y. Aggregate demand depends on real output and real money balances, $m - p$; m is the nominal money stock, p the price level; u^a is a demand disturbance (IV.5). Demand for labour, ℓ^d, is determined by equating the marginal product of labour to the real wage. w_t is the money wage rate. The marginal product of labour has a random component, u_t^ℓ (IV.7). The supply of labour depends on the real wage (IV.7). Actual employment is equal to the demand for labour (IV.8).[10/] The production function is given in (IV.9). u_t^a and u_t^ℓ are white noise disturbances.

If the labour market is characterized by an instantaneously flexible money wage $\ell_t^d = \ell_t^s$ and the equilibrium money wage is given by:

(IV.10) $w_t = p_t + \frac{u_t^\ell}{1+\beta\gamma}$

Now assume that the money wage for period t has to be predetermined in period $t-1$, i.e. that is has to be chosen in a non-contingent, open-loop manner. We assume it is chosen in such a way that the expected (as of $t-1$) excess demand or supply in the labour market is zero, i.e. w_t is given by:

$$\text{(IV 10')} \qquad w_t = E(p_t + \frac{u_t^{\ell}}{1+\beta\gamma} \mid I_{t-1}) = \hat{p}_{t|t-1}$$

From (IV.9), (IV.8), (IV.6) and (IV.10') it then follows that

$$\text{(IV.11)} \qquad y_t = \delta\beta^{-1}(p_t - \hat{p}_{t|t-1}) + \delta\beta^{-1}u_t^{\ell}$$

This is one possible derivation of the Sargent-Wallace [1975] supply function, although not the one they prefer. From (IV.4) and (IV.5) we obtain:

$$\text{(IV.12)} \qquad y_t = (1 - \alpha_1)^{-1} \alpha_2 m_t - (1 - \alpha_1)^{-1} \alpha_2 p_t + (1 - \alpha_1)^{-1} u_t^a$$

Equating (IV.11) and (IV.12), solving for p_t and taking expectations as of $t - 1$ 11/ we get:

$$p_t - \hat{p}_{t|t-1} = \frac{(1-\alpha_1)^{-1}\alpha_2}{(1-\alpha_1)^{-1}\alpha_2+\delta\beta^{-1}} \left(m_t - \hat{m}_{t|t-1}\right) + \frac{(1-\alpha_1)^{-1}}{(1-\alpha_1)^{-1}\alpha_2+\delta\beta^{-1}} u_t^a$$

$$- \frac{\delta\beta^{-1}}{[(1-\alpha_1)^{-1}\alpha_2+\delta\beta^{-1}]} u_t^{\ell}$$

$$\text{(IV.13)} \qquad y_t = \frac{\delta\beta^{-1}(1-\alpha_1)^{-1}\alpha_2}{(1-\alpha_1)^{-1}\alpha_2+\delta\beta^{-1}} \left(m_t - \hat{m}_{t|t-1}\right) + \frac{\delta\beta^{-1}(1-\alpha_1)^{-1}}{(1-\alpha_1)^{-1}\alpha_2+\delta\beta^{-1}} u_t^a$$

$$+ \frac{\delta\beta^{-1}[(1-\alpha_1)^{-1}\alpha_2+\delta\beta^{-1}-1]\, u_t^{\ell}}{(1-\alpha_1)^{-1}\alpha_2+\delta\beta^{-1}}$$

If m_t is set in open-loop fashion, or if m_t is some linear function of I_{t-1}, the information set available to both public and private agents when w_t was set, then $m_t = \hat{m}_{t|t-1}$. If, however, m_t can be set as a known (in period t - 1) function of I_t, then such a contingent rule will affect the probability density function of y_t. Consider e.g. the following instantaneous feedback rule:

$$\text{(IV.14)} \quad m_t = \pi_a u_t^a + \pi_\ell u_t^\ell$$

It is easily seen that y_t can be stabilized perfectly by choosing π_a and π_ℓ such that

$$\text{(IV.15a)} \quad \pi_a = -\alpha_2^{-1}$$

and

$$\text{(IV.15b)} \quad \pi_\ell = \frac{1-\delta\beta^{-1}-(1-\alpha_1)^{-1}\alpha_2}{(1-\alpha_1)^{-1}\alpha_2}$$

If the money wage had to be set two periods in advance, monetary feedback rules relating the current money supply either to the current information set or to last period's information set will affect the behaviour of real output. If m_t were to be a deterministic linear function of I_{t-2} (or of I_{t-i}, $i > 2$) no effect on real output is obtained in this model. It will be shown next that in a slightly different model monetary policy effectiveness can be present even if the public sector cannot respond faster to new information than the private sector, or indeed even if the reverse is the case.

2) Policy effectiveness through revisions in forecasts of future instrument values

Consider the following very simple macroeconomic model of a small open economy with perfect capital mobility and a freely floating exchange rate:

$$(IV.16) \quad m_t - p_t = \alpha_1 y_t - \alpha_2 r_t + u_t^m \qquad \alpha_1, \alpha_2 > 0$$

$$(IV.17) \quad y_t = \beta(p_t - \hat{p}_{t|t-1}) + u_t^y \qquad \beta > 0$$

$$(IV.18) \quad r_t = r_t^* + \hat{e}_{t+1|t} - e_t$$

$$(IV.19) \quad p_t = e_t + p_t^*$$

All variables except for interest rates are in logarithms. (IV.16) is a standard LM curve. r_t is the domestic nominal interest rate, u_t^m a monetary disturbance. (IV.17) is a Sargent-Wallace supply function. u_t^y is a supply disturbance. (IV.18) states that the domestic interest rate equals the exogenous world interest rate, r^*, plus the expected proportional rate of depreciation of the exchange rate e. (This assumes perfect capital mobility and risk neutrality). Note that the future exchange rate expectation linking r_t with r_t^* is conditioned at time t. This reflects the assumption that financial markets clear each period and that the portfolio allocation decisions for period t can be made instantaneously on the basis of the information available in that period. This stands in contrast to the labour market where the period t money wage has to be decided on (in an open-loop manner) in period t-1. The "law of one price" holds instantaneously and equates the domestic price level to the exogenous world price level, p_t^* plus the exchange rate. To save on algebra we set $p_t^* = r_t^* = 0$ for all t.

From the earlier discussion it is clear that if m_t could be made a function of I_t , then such an instantaneous policy response function would alter the behaviour of y_t , since y_t depends on private forecasts of p_t (and therefore of m_t) made in period t-1 on the basis of I_{t-1}. In this example, however, y_t can be influenced by a monetary feedback rule even if m_t is made a function of I_{t-1} or more generally of I_{t-i} , $i \geq 1$. The reason is that p_t , (and therefore $p_t - \hat{p}_{t|t-1}$ and y_t) depends, through the LM curve, the interest parity condition and the law of one price, on expectations of future price levels (and future money supplies) formed in period t. If m_t is a known linear function of I_{t-1} , $m_t = f(I_{t-1})$ say, current period information cannot influence m_t . Such information can influence $m_{t+1} = f(I_t)$, however. In models such as (IV.6) - (IV.19), therefore, which incorporate expectations of future endogenous variables conditioned at different dates ($\hat{p}_{t|t-1}$ and $\hat{e}_{t+1|t}$) monetary feedback rules can affect real output via (changes in) anticipations of *future* money supplies. (Turnovsky [1980], Weiss [1980], Buiter [1980 c, e, f], Buiter and Eaton [1980]).

Assuming stability, the model of equations (IV.16) - (IV.19) can be solved for $p_t - \hat{p}_{t|t-1}$ and thus for y_t . This yields

(IV.20)
$$y_t = \frac{\beta}{1+\alpha_1\beta+\alpha_2}\left(m_t - \hat{m}_{t|t-1}\right) + \frac{\beta\alpha_2}{(1+\alpha_1\beta+\alpha_2)(1+\alpha_2)}\sum_{i=o}^{\infty}\left(\frac{\alpha_2}{1+\alpha_2}\right)^i\left(\hat{m}_{t+1+i|t} - \hat{m}_{t+1+i|t-1}\right) - \left(\frac{\beta u_t^m - (1+\alpha_2)u_t^y}{1+\alpha_1\beta+\alpha_2}\right)$$

Real output and the price forecast error $p_t - \hat{p}_{t|t-1}$ depend on the revision, between t-1 and t , in the forecast of the money supply in period t and in all future periods. To see the stabilization role of lagged monetary feedback rules, consider the policy rule of (IV.21) which makes the current money stock a function of all past random disturbances

(IV.21) $$m_t = \sum_{i=1}^{\infty} [\pi_{y,i}\, u^y_{t-i} + \pi_{m,i}\, u^m_{t-i}]$$

Taking expectations of current and future m conditional on I_t and on I_{t-1} using (IV.21) and substituting the resulting expressions in (IV.20) we get:

(IV.22) $$y_t = \frac{\beta\alpha_2}{(1+\alpha_1\beta+\alpha_2)(1+\alpha_2)} \sum_{i=o}^{\infty} \left(\frac{\alpha_2}{1+\alpha_2}\right)^i \left(\pi_{y,1+i}\, u^y_t + \pi_{m,1+i}\, u^m_t\right) - \left(\frac{\beta u^m_t - (1+\alpha_2)\, u^y_t}{1+\alpha_1\beta+\alpha_2}\right)$$

It is possible to stabilize output perfectly by choosing the $\pi_{y,i}$ and $\pi_{m,i}$ such that:

(IV.23a) $$1 + \alpha_2 + \frac{\beta\alpha_2}{1+\alpha_2} \sum_{i=o}^{\infty} \left(\frac{\alpha_2}{1+\alpha_2}\right)^i \pi_{y,1+i} = 0$$

and

(IV.23b) $$-\beta + \frac{\beta\alpha_2}{1+\alpha_2} \sum_{i=o}^{\infty} \left(\frac{\alpha_2}{1+\alpha_2}\right)^i \pi_{m,1+i} = 0$$ 12/

E.g. output can be stabilized perfectly by responding, in period t, only to u^y_{t-1} and u^m_{t-1}. This involves setting $\pi_{y,1+i} = \pi_{m,1+i} = 0$, $i \geqslant 1$

and

$$\text{(IV.24a)} \quad \pi_{y,1} = -\frac{(1+\alpha_2)^2}{\beta\alpha_2}$$

$$\text{(IV.24b)} \quad \pi_{m,1} = \frac{1+\alpha_2}{\alpha_2}$$

Alternatively, perfect stabilization of output could be achieved by responding, in period t, only to u^y_{t-2} and u^m_{t-2} or to even earlier random disturbances or by responding to some or all of the past disturbances according to (IV.23a) or (IV.23b). Even if the government is at an informational *disadvantage vis à vis* the private sector, in the sense that it receives information on realizations of u^m_t and u^y_t later than private agents do, a known feedback rule using its inferior information will influence private sector behaviour.13/ This is achieved by the government committing itself, in advance, to respond in a known manner to the random disturbances in some future period. In the example given here, it is irrelevant when the government responds to the disturbances. An equivalent effect on real output can be achieved via instantaneous response, lagged response or some mixture of the two. This suggests the following proposition.

Proposition 2. If in the "semi-reduced form" real variables depend on revisions in private sector forecasts of future instrument values, known deterministic feedback rules will affect real behaviour. Such revisions in future policy instrument forecasts will enter the semi-reduced form of the model if expectations of future endogenous variables conditioned at different dates are present in the structural equations of the model.

This suggests that equations like (IV.1') should be augumented with a term like $\sum_{k=1}^{R_1} \sum_{i=-T_3}^{T_2} \sum_{j=o}^{S_2} d_{ijk}(\hat{x}_{t+i|t-j} - \hat{x}_{t+i|t-j-k})$.

Anticipated future policy

In equations such as (IV.1), which have been the starting point for empirical work in this area, only anticipated current and past instrument values enter as arguments. When the role of monetary policy is being investigated, however, there are good theoretical reasons for believing that real variables will be functions of anticipated *future* monetary growth. This is illustrated with the simple money,capital and growth model of equations (IV.25) - (IV.29). It is taken from Lucas [1975], which in turn is a development of Tobin [1965]. (See also Fischer [1979]).

(IV.25) $k_{t+1} = \alpha_1 r_{Kt} - \alpha_2 r_{Mt} + \alpha_3 k_t$ $\qquad \alpha_1, \alpha_2, \alpha_3 > 0$

$\alpha_1 > \alpha_2, \alpha_3 < 1$

(IV.26) $m_{t+1} - p_t = - \beta_1 r_{Kt} + \beta_2 r_{Mt} + \beta_3 k_t$ $\qquad \beta_1, \beta_2, \beta_3 > 0$

$\beta_2 > \beta_1, \beta_3 < 1$

(IV.27) $r_{Kt} = - \delta_1 k_{t+1}$ $\qquad \delta_1 > 0$

(IV.28) $r_{Mt} = p_t - p_{t+1}$

(IV.29) $m_{t+1} - m_t = \mu_t$

For notational simplicity all constants are omitted. Variables other than rates of return are in logarithms. The constant labour force, which is always fully employed, is scaled to unity. k_t is the capital stock, r_{Kt} the real rate of return on capital and r_{Mt} the real rate of return on non-interest-bearing money. There is no uncertainty, so rational expectations amount to perfect foresight. (IV.25) and (IV.26) state that the desired (and actual) end-of-periods stocks of capital and real money balances depend on the real rates of return on the two assets and on the initial capital stock. The rate of return on capital equals the marginal product of capital (IV.27). The rate of return on money is minus the (expected) rate of inflation. Let $m_t = \ln M_t$ μ_t is the proportional rate of growth of the money supply in period t : $M_{t+1} = (1+\mu_t)M_t$. Therefore $m_{t+1} \approx \mu_t + m_t$.

To find a rational expectations solution for (IV.25) - (IV.29), try a solution for k_t and p_t of the following form:

(IV.30a) $$k_{t+1} = \pi_{11} k_t + \pi_{12} m_t + \sum_{i=o}^{\infty} \psi_{k,i} \mu_{t+i}$$

(IV.30b) $$p_t = \pi_{21} k_t + \pi_{22} m_t + \sum_{i=o}^{\infty} \psi_{p,i} \mu_{t+i}$$

Substituting (IV.27), (IV.28) and (IV.29) into (IV.25) and (IV.26), using (IV.30a) and (IV.30b) and rearranging, we obtain another set of equations of the same form as (IV.30a) and (IV.30b). Equating coefficients between these two sets of equations we obtain the following solutions for the π_{ij}, $\psi_{k,i}$ and $\psi_{p,i}$.

(IV.31a) $$\pi_{11} = - \alpha_1 \delta_1 \pi_{11} - \alpha_2 \pi_{21} (1-\pi_{11}) + \alpha_3$$

(IV.31b) $$\pi_{12} = 0$$

(IV.31c) $-\pi_{21} = \beta_1 \delta_1 \pi_{11} + \beta_2 \pi_{21} (1-\pi_{11}) + \beta_3$

(IV.31d) $\pi_{22} = 1$

(IV.32a) $\psi_{k,o} = [1 + \alpha_1 \delta_1 - \alpha_2 \pi_{21}]^{-1} \alpha_2 (1 - \psi_{p,o})$

(IV.32b) $\psi_{k,i} = [1 + \alpha_1 \delta_1 - \alpha_2 \pi_{21}]^{-1} \alpha_2 (\psi_{p,i-1} - \psi_{p,i})$ $\quad i > 0$

(IV.32c) $\psi_{p,o} = (1 + \beta_2)^{-1} [1 + \beta_2 - (\beta_1 \delta_1 - \beta_2 \pi_{21}) \psi_{k,o}]$

(IV.32d) $\psi_{p,i} = (1 + \beta_2)^{-1} [\beta_2 \psi_{p,i-1} - (\beta_1 \delta_1 - \beta_2 \pi_{21}) \psi_{k,i}]$ $\quad i > 0$

Equations (IV.31a) and (IV.31c) define two solutions for π_{11} and π_{21}. It can be shown (Lucas [1975]) that the stable solution is characterized by:

(IV.33a) $\frac{\alpha_3}{1+\alpha_1\delta_1} < \pi_{11} < 1$

(IV.33b) $\pi_{21} < 0$

Since $\pi_{12} = 0$ and $\pi_{22} = 1$, money is neutral in this model. An increase in m_t, the level of the money stock, leads to an equal proportional increase in p_t and leaves k_{t+1} unaffected.14/ Money is not, however, super-neutral. Different current and future rates of growth of the money stock, i.e. different μ_{t+i}, $i \geqslant 0$, will be associated with different paths for the capital stock. Money will only be super neutral if $\psi_{k,j} = 0$, for all j. From (IV.32a) and (IV.32b) it is apparent that if $\alpha_2 = 0$, i.e. if the demand for capital is independent of the real rate of return on money, then all values of $\psi_{k,i}$ will be zero. If $\alpha_{2} \neq 0$, $\psi_{k,o} = 0$ only if $\psi_{p,o} = 1$: an increase in the current period rate of monetary growth (μ_t) by one percentage point raises the current price level by one percent. If $\psi_{k,o} = 0$, $\psi_{k,1} = 0$ only if $\psi_{p,1} = \psi_{p,o} = 1$ (IV.32b). This however is possible only if $\beta_2 = +\infty$ (IV.32d), i.e. if the demand for real money balances is infinitely elastic with respect to the rate of return on money. This forces the price level to be constant over time, regardless of the behaviour of future rates of monetary growth. If $\psi_{k,i}$ is to be equal to zero for all other i as well, it now follows that all other $\psi_{p,i}$ will equal unity. From (IV.30b) it is then clear that for any constant positive value of μ_t , the current price level will be infinite!

Ruling out the two special cases $\alpha_2 = 0$ and $\beta_2 = +\infty$, the path of the capital stock will therefore not be invariant under alternative fully perceived fixed rules for the future rates of growth of the money supply. Different anticipated future rates of monetary growth will be associated with different anticipated inflation rates. The portfolio allocation between money and real capital will not be invariant to this "inflation tax". In particular, the steady-state capital stock (found by setting $k_t = k_{t+1}$, $m_t - p_t = m_{t+1} - p_{t+1}$ and $\mu_t = \mu$ in (IV.25) - (IV.29)) is given by

$$\text{(IV.34)} \qquad k = (1 + \alpha_1 \delta_1 - \alpha_3)^{-1} \alpha_2 \mu$$

The long-run capital stock is an increasing function of the rate of monetary growth if $\alpha_2 > 0$. For completeness, the following well-known monetary policy effectiveness proposition can now be stated.

Proposition 3. If the expected rate of inflation affects the portfolio choice between money and real assets, alternative open-loop policies for future monetary growth will have real effects.

This monetary policy effectiveness result is very different from those stated in propositions (1) and (2). The first two propositions (policy response interval shorter than private forecast horizon and revisions in policy instrument forecasts) rely on contingent policy rules influencing private forecast errors. Such policies are *stabilization* policies that influence deviations of real variables from their full information or equilibrium levels. In the absence of uncertainty there would be no role for them. Proposition 3 relies on the *structural* or *allocative* role of monetary policy. "Effectiveness" here refers to the ability to influence the equilibrium values of real variables, not to the capacity to influence deviations from these equilibrium values. Here effectiveness holds for fixed rules as for contingent rules and is not dependent on the presence of uncertainty. In a stochastic model of capital, money and growth, monetary policy can play both a stabilization role and an allocative role.

The potential importance of anticipated future instrument values suggests that equation (IV.1) or (IV 1') should have added to it a term such as

$$\sum_{i=o}^{T_4} \sum_{j=o}^{S_3} e_{ij} \hat{x}_{t+i|t-j} \quad .$$

While it is hard to assess the empirical significance of the inflation tax argument,Feldstein [1979] has argued -- it is not quite clear how seriously in that the dead-weight loss associated with a higher rate of inflation in the U.S. may well be infinite! It should be possible to discover the presence of such effects in empirical work.

The implications of the results of this Section for the fixed vs. flexible rules debate are straightforward. Unless policy instruments affect real behaviour only via contemporaneous inference errors, i.e. only via terms such as $x_{\tau} - \hat{x}_{\tau|\tau}$, deterministic feedback rules will have real effects. If anticipated past or future instrument values have real effects, alternative open-loop rules too will alter real behaviour. In models with uncertainty, the optimal fixed rule will never dominate the optimal flexible rule.

Anticipated policies without real effects: an empty box?

Are there policy instruments for which a plausible theoretical case can be made that they have no effects to the extent that they are anticipated? The discussion in this Section has so far been entirely in terms of monetary policy. There is only one other policy action for which neutrality has been argued on theoretical grounds. This is the substitution of government borrowing for lump-sum taxation, keeping constant the size and composition of the government's real spending programme. All other fiscal policy changes, on the spending side and on the revenue side, are likely to have real effects even in classical market-clearing models because they alter the constraints faced by private agents in a way that cannot be neutralized by utility maximizing and profit maximizing private actions. When such policy changes are anticipated their effects are in general different from what they are when they come as a surprise. The degree of confidence with which these expectations are held will also matter for the outcome, as will the length of the interval between the "announcement" of a previously unanticipated policy change and its subsequent implemention. Finally, the extent to which the policy change is expected to be permanent or transitory will make a difference. It is, however, very difficult to come up with interesting models in which the solution trajectories of all real variables are invarient under alternative fully anticipated paths for the fiscal policy instruments (see e.g. Buiter [1977, 1979a, 1980c, d], Fair [1978]).

This leaves only the two "stabilization" instruments, monetary policy and changing the borrowing-taxation mix, as candidates for the "neutral when anticipated" category. The case for debt neutrality was restated elegantly by Barro [1974]. His conclusion that if 1) private agents rationally foresee the future tax obligations "required" to service current government borrowing and 2) private agents are linked to later and earlier generations via an operative voluntary intergenerational chain of gifts or bequests, then government borrowing (or unfunded social security retirement programmes) will not affect the real trajectories of consumption and capital formation, has since been shown not to be robust. (Buiter [1979b, 1980b], Buiter and Tobin [1979], Tobin and Buiter [1980], Carmichael [1979]). A presumption exists that the substitution of borrowing for lump-sum taxation will crowd out private saving in the short run and reduce the capital-labour ratio in the long run.

Empirical work on measuring the degree of (non)-neutrality of public sector debt has so far been inconclusive. Felstein [1974] found a very strong negative effect of social security wealth on private saving, which was lowered by as much as one third. Barro [1978] found no significant effect. Using Barro's data Feldstein [1978] again reported a significant depressing effect of social security wealth on private saving. The value of this work hinges crucially on the construction of the social security wealth variable. In essence, estimates of social security wealth have been obtained by extrapolating current or past payment/benefit ratios over the remaining life span of the economically active population. This is one more area of research where use of the rational expectations hypothesis could be very fruitful, as it is the present value of *anticipated* future payments and benefits that is the crucial explanatory variable.

The case against monetary superneutrality has already been argued. It is important to note that debt neutrality is a logical prerequisite for neutrality of the *level* of the money stock. If government bonds are net wealth (or more accurately, if the real value of government interest-bearing debt enters as an argument in some private sector behavioural relationship(s)), an equal proportional increase in the stock of money and in all money prices will not be neutral if nominally denominated, fixed price interest-bearing government debt is held by the private sector.

Even if no strong theoretical case can be made for monetary neutrality and superneutrality, the empirical magnitudesof the non-neutralities could still be insignificant. Elsewhere (Buiter [1980f]) I have discussed some of the problems associated with the empirical work inspired by Barro [1977, 1978], (see also Barro and Rush [1980], Attfield, Demery and Duck [1979a, b]), which attempts to evaluate the real effects of unanticipated and anticipated monetary growth using equations such as (IV.1). One problem is the omission from (IV.1) of private sector forecast horizons of different lengths, of revisions in forecasts of future instrument values and of anticipations of future monetary growth. Another problem is that the effect of unanticipated money on output (or unemployment) is identified only if the implausible *a priori* constraint is imposed that money does not respond to unanticipated output (or unemployment). No empirical resolution of these issues is as yet available.

V The time inconsistency of optimal plans

The fourth argument in favour of fixed rules takes aim at the application of traditional optimal control techniques based on dynamic programming to the derivation of optimal economic policies in models with optimizing agents endowed with rational expectations, in which the current state depends on expectations of future states and therefore on expectations of future disturbances, exogenous variables and policy choices. We saw in Section I that traditional optimal control techniques such as stochastic dynamic programming lead to optimal policy rules that in models with uncertainty must be expressed in feedback or closed-loop form. Kydland and Prescott [1977] have shown that policies derived by dynamic programming, which they call "time consistent" policies,[15/] may be suboptimal in models with optimizing agents endowed with rational expectations of the future, because such time consistent policies fail to allow for the effect of anticipated future instrument values on current and past states. The optimal policy in such models, they argue, is a time-inconsistent rule. Given the inappropriateness of dynamic programming methods the search for a good policy rule should be limited to a comparison (analytically or by simulation methods) of alternative policy rules in order to select the one with the most attractive operating characteristics (see also Prescott [1977]). Kydland and Prescott's proposition is quite distinct from the New Classical proposition that only unanticipated stabilization policy can have real effects. It applies with full force only if anticipated future values of policy instruments affect real variables.

Traditional dynamic programming techniques do not allow for the impact of future policy measures on the current state through changes in current and past behaviour induced by anticipation of these future policy measures. This does not matter for *causal* or backward-looking models, such as the one given in equation (I.4). Here the current state is, in the structural model, a function only of the past state and the current values of the "forcing variables", that is the policy instruments, the exogenous variables and the disturbance term. It matters greatly in *non-causal* or forward-looking models, such as the one given in equation (V.1) in which, in the structural model, the current state depends on the anticipated future state(s) as well as, possibly, on the past state and the current values of the forcing variables.

$$(V.1) \quad y_t = A_t y_{t-1} + C_t x_t + b_t + u_t + D_t E(y_{t+1} | I_t) \ .$$

By repeated substitution for $E(y_{\tau+1} | I_\tau)$, equation (V.1) can be solved for y_t as a function of y_{t-1} and of the current and anticipated future values of the instruments, the exogenous variables and the disturbances. The application of dynamic programming, which takes y_{t-1} as given when the optimal value of x_t is chosen, runs into trouble here because y_{t-1} depends on expectations, formed in period $t-1$, of x_t, x_{t+1} etc.

The analysis of this section shows that while Kydland and Prescott's rejection of dynamic programming methods in non-causal models is correct, the optimal (time-inconsistent) policy will, in models with uncertainty, still be a contingent, closed-loop rule. Time-inconsistency creates two problems, one for economists and one for economic policy makers. The problem facing economists is that a particular method or technique of optimization in dynamic models -- one which has proven very useful in the natural sciences and in engineering -- is inappropriate in the social sciences when expectations of the future affect current outcomes. New optimization techniques for non-causal models must be developed (see e.g. Chow [1980]).

Even if these technical problems are overcome and the optimal time-inconsistent rule has been computed, as in the simple example of this section, the problem of pursuing or implementing time-inconsistent policies remains. Since, almost by definition, rational, non-cooperative behaviour in sequential models is time-consistent behaviour, how can the policy maker constrain himself to pursue optimal but time-inconsistent policies and how can he convince private agents that this is what he will do? No solution is offered here to the problem of adopting and executing time-inconsistent optimal plans. We do, however, establish that the rule or "constitution" representing the optimal time-inconsistent policy will be a contingent rule or a flexible constitution. In non-causal models with uncertainty the optimal fixed rule will be both time-inconsistent and dominated by the optimal (time-inconsistent) feedback rule. E.g. in the previous section, the lagged feedback rules that perfectly stabilize real output by influencing revisions in expectations of future money supplies are time-inconsistent: past anticipations of the current money supply affect past output; this, of course, is a bygone when the current period arrives and a value is assigned to the current money stock.

A simple stochastic model with time-inconsistency

The model of equations (V.2) - (V.4) is a stochastic, linear-quadratic version of the two-period model of Kydland and Prescott [1977].

$$\text{(V.2)} \quad W = E(k_1(y_1-a_1)^2 + k_2(y_2-a_2)^2 + k_3(x_1-a_3)^2 | I_1) \qquad k_1, k_2, k_3 > 0$$

$$\text{(V.3)} \quad y_t = \alpha y_{t-1} + \gamma x_t + \delta E(x_{t+1}|I_t) + u_t \qquad t = 1, 2 \quad \alpha, \gamma, \delta \neq 0$$

$$\text{(V.4a)} \quad y_o = 0$$

$$\text{(V.4b)} \quad x_3 = 0$$

(V.2) is the objective function the policy maker aims to minimize. y_t is the state variable, x_t the policy instrument and u_t a white noise random disturbance. An initial condition for y_0 and a terminal condition for x_3 are given in (V.4a,b). The constraint faced by the policy maker is the simple model of (V.3). One interpretation of (V.3) is as follows. Let real output, y_t depend on the expected real rate of return and, because of adjustment costs, on lagged output. If money is the only asset, the expected real rate of return is minus the expected rate of inflation. The supply function is therefore:

$$y_t = \mu_1 y_{t-1} - \mu_2 (p_t - E(p_{t+1}|I_t)) + \varepsilon_t .$$

ε_t is a white noise random disturbance term. μ_1, $\mu_2 > 0$. If the country is small in the world commodity market and instantaneous purchasing power parity prevails, we have

$$p_t = e_t + p_t^*$$

e_t is the logarithm of the exchange rate, p_t^* the logarithm of the world price level which is assumed to behave like a white noise disturbance term. The exchange rate is the policy instrument. Substituting the p.p.p. relationship into the supply function we get

$$y_t = \mu_1 y_{t-1} - \mu_2 e_t + \mu_2 E(e_{t+1}|I_t) + \varepsilon_t - \mu_2 p_t^* .$$

This corresponds to (V.3) with $\mu_1 = \alpha$, $\mu_2 = \delta = -\gamma$; $\varepsilon_t - \mu_2 p_t^* = u_t$.

More generally, we can interpret a model like (V.3) as representing the optimizing behaviour of the private sector, which takes as given the behaviour of the policy maker, represented by x_t and $E(x_{t+1}|I_t)$. We assume that I_t , the information set conditioning expectations formed in period t , contains the model, including any deterministic policy rule, y_{t-1} and x_t but not y_t or u_t. x_t also has to be set before y_t and u_t are observed. Private agents have rational expectations about future policy behaviour but are "Stackelberg followers". By taking x_t and $E(x_{t+1}|I_t)$ as given they do not allow, when selecting the optimal values of their private controls, for any response of the policy maker to their choices. Private optimizing behaviour is subsumed in the constant parameters α, γ, δ. The policy maker is the "Stackelberg leader". When selecting his optimal course of action he allows for the private sector's response to his choice of instruments, as represented in equation (V.3). This representation of public-private sector interaction as an asymmetric leader-follower non-cooperative game is quite common (see e.g. Fischer [1980]). Note that it is possible (but not necessary) for the (explicit) public sector objective function (V.2) to be the same as the (implicit) private sector objective function.

The model of (V.3) is non-causal: the current state, y_t, depends on an anticipated future instrument value. This suggests that time-consistent policies derived by dynamic programming will be sub-optimal. The time-consistent value of x_2 will be chosen to minimize $E\left(k_2(y_2-a_2)^2|I_2\right)$, taking as given y_1 (and x_1). While there is no doubt that y_1 will be a bygone once period 2 has arrived, y_1 is, from (V.3) a function of $E(x_2|I_1)$. Therefore, to choose the time-consistent value for x_2 on the assumption that y_1 is unaffected by the choice of x_2 will in general be suboptimal.

It is also clear that any open-loop rule for x_t is likely to be suboptimal. When x_2 is set in period 2, u_1 is known. u_1 is unknown, however, at the beginning of period 1, when any rule, fixed or flexible, for x_1 has to be announced. A contingent rule permits a known response of x_2 to the as yet unknown realization of the random variable u_1. A fixed rule permits no such response and will therefore be suboptimal.

The optimal (but time-inconsistent) rule both permits a response of x_2 to the new information u_1 and allows for the dependence of y_1 on $E(x_2|I_1)$. It is derived as follows. Substitute the constraints (V.3) - (V.4a,b) into the objective function (V.2). This yields

$$\text{(V.5)} \quad W = E\left[k_1\left(\gamma x_1 + \delta E(x_2|I_1) + u_1 - a_1\right)^2 + k_2\left(\alpha\gamma x_1 + \alpha\delta E(x_2|I_1) + \gamma x_2 + \alpha u_1 + u_2 - a_2\right)^2 + k_3(x_1 - a_3)^2 \,\middle|\, I_1\right]$$

Restricting ourselves to linear policy rules, the difference between x_2 and $E(x_2|I_1)$ will be a linear function of the new information that has accrued between periods 1 and 2. This new information consists of u_1. Therefore

$$\text{(V.6)} \quad x_2 = E(x_2|I_1) + \pi u_1$$

π is a linear policy response function, to be chosen by the policy maker. Substituting (V.6) into (V.5) we get:

$$\text{(V.7)} \quad W = E\left[k_1\left(\gamma x_1 + \delta E(x_2|I_1) + u_1 - a_1\right)^2 + k_2\left(\alpha\gamma x_1 + (\alpha\delta+\gamma)\, E(x_2|I_1) + (\alpha+\gamma\pi)\, u_1 + u_2 - a_2\right)^2 + k_3(x_1-a_3)^2 \,\middle|\, I_1\right]$$

(V.7) is now minimized with respect to x_1 , $E(x_2|I_1)$ *and* π . This yields optimal values x_1^* , $E(x_2|I_1)^*$ and π^* given by

(V.8a) $$x_1^* = \frac{\gamma^2[a_1(\alpha\delta+\gamma)-a_2\delta]k_1k_2 + a_3\delta^2k_1k_3 + a_3(\alpha\delta+\gamma)^2k_2k_3}{\gamma^4k_1k_2 + \delta^2k_1k_3 + (\alpha\delta+\gamma)^2k_2k_3}$$

(V.8b) $$E(x_2|I_1)^* = \frac{\gamma^3[a_2-\alpha a_1]k_1k_2+\delta[a_1-\alpha a_3]k_1k_3 + (\alpha\delta+\gamma)[a_2-\alpha\gamma a_3]k_2k_3}{\gamma^4k_1k_2 + \delta^2k_1k_3 + (\alpha\delta+\gamma)^2k_2k_3}$$

(V.8c) $$\pi^* = -\alpha\gamma^{-1}$$

The optimal (time-inconsistent) feedback rule given in (V.8a, b, c) can be contrasted with the optimal (time-inconsistent) open-loop rule. For any non-stochastic fixed rule, $x_2 = E(x_2|I_1)$. The optimal open-loop rule, $\bar{x}_1$, $\bar{x}_2$ is therefore given by:

(V.9a) $$\bar{x}_1 = x_1^*$$

(V.9b) $$\bar{x}_2 = E(x_2|I_1)^*$$

The optimal feedback rule can now be seen to consist of two parts, the optimal open-loop rule plus a (linear) response to the disturbance or "innovation". The response coefficient $\pi^* = -\alpha\gamma^{-1}$ is chosen so as to exactly neutralize the effect of u_1 on y_2. By substituting the optimal instrument values (V.8a, b, c) or (V.9a, b) into the objective function (V.5) we can evaluate the expected loss under the feedback and the open-loop policies. Let W^* be the expected loss under the optimal feedback policy and $\bar{W}$ the expected loss under the optimal open-loop policy. σ_u^2 is the variance of u_t, $t = 1, 2$. It follows by inspection that

(V.10) $\overline{W} - W^{*} = k_2\, \alpha^2\, \sigma_u^2 > 0$

Thus, provided there is uncertainty ($\sigma_u^2 > 0$), provided u_1 affects y_2 ($\alpha \neq 0$) and provided y_2 enters the objective function ($k_2 > 0$), the optimal feedback policy dominates the optimal open-loop policy. If there is no uncertainty, as in the two-period example of Kydland and Prescott [1977], the two policies are equivalent.

The optimal time-inconsistent feedback rule not only dominates the optimal time-inconsistent fixed rule. It is also superior to the time-consistent policy derived by stochastic dynamic programming. The ranking of the time-consistent policy and the optimal fixed rule is ambiguous, however. The time-consistent solution for x_2 and x_1 is derived by first selecting the value of x_2 that minimizes $E(k_2(y_2 - a_2)^2 | I_2)$, taking as given the value of y_1. Since $y_2 = \alpha y_1 + \gamma x_2 + u_2$, the time-consistent solution for x_2 is given by

(V.11a) $\tilde{x}_2 = [a_2 - \alpha y_1]\gamma^{-1}$

This implies that $E(y_2 - a_2 | I_2) = E(y_2 - a_2 | I_1) = 0$. The time-consistent value of x_1 is then derived by choosing the value of x_1 that minimizes (V.2), assuming that in period 2, x_2 will be set according to (V.11a). The solution for x_1 is:

(V.11b) $$\tilde{x}_1 = \frac{[(\alpha\delta+\gamma)a_1 - \delta a_2]\gamma^2 k_1 + (\alpha\delta+\gamma)^2 a_3 k_3}{k_1\gamma^4 + k_3(\alpha\delta+\gamma)^2}$$

The time-consistent solution for x_1 and x_2 in (V.11a, b) differs from the optimal time-inconsistent feedback rule in (V.8a, b, c) and will therefore be inferior to it.[16] We can compare the expected loss under the optimal open-loop rule, $\bar{W}$, and under the time-consistent policy, $\tilde{W}$, by substituting (V.9a, b), respectively (V.11a, b) into the objective function (V.5), noting that $E(\tilde{x}_2|I_1) = [a_2 - \alpha\gamma\bar{x}_1](\alpha\delta+\gamma)^{-1}$ and $\tilde{x}_2 = a_2\gamma^{-1} - \alpha\tilde{x}_1 - \alpha\gamma^{-1}\delta E(\tilde{x}_2|I_1) - \alpha\gamma^{-1}u_1$ $= (a_2 - \alpha\gamma\tilde{x}_1)(\alpha\delta+\gamma)^{-1} - \alpha\gamma^{-1}u_1$. The algebra is simplified if we set $a_1 = a_2 = 0$. After rearranging terms we get:

$$\text{(V.12)} \quad \bar{W} - \tilde{W}_u = k_1\left[\left(\frac{a_3\gamma^2(\alpha\delta+\gamma)k_2k_3}{\gamma^4k_1k_2+\delta^2k_1k_3+(\alpha\delta+\gamma)^2k_2k_3}\right)^2 - \left(\frac{a_3\gamma^2(\alpha\delta+\gamma)k_2k_3}{\gamma^4k_1k_2+(\alpha\delta+\gamma)^2k_2k_3}\right)^2\right]$$

$$+ k_2\left(\frac{a_3\delta\gamma^2k_1k_3}{\gamma^4k_1k_2+\delta^2k_1k_3+(\alpha\delta+\gamma)^2k_2k_3}\right)^2$$

$$+ k_3\left[\left(\frac{a_3\gamma^4k_1k_2}{\gamma^4k_1k_2+\delta k_1k_3+(\alpha\delta+\gamma)^2k_2k_3}\right)^2 - \left(\frac{a_3\gamma^4k_1k_2}{\gamma^4k_1k_2+(\alpha\delta+\gamma)^2k_2k_3}\right)^2\right]$$

$$+ k_2\,\alpha^2\,\sigma_u^2$$

Because of the last term, $k_2\,\alpha^2\,\sigma_u^2$, it is clear that if there is sufficient uncertainty in the model (i.e. for sufficiently large σ_u^2) the expected loss under the time-consistent policy will be less than under the optimal open-loop rule. It is easily checked[17] that the first three terms on the right-hand side of (V.12) measure the difference between the expected loss under the optimal open-loop rule and under the time-consistent policy for the case in which there is no uncertainty. Since without uncertainty the optimal open-loop rule is the globally optimal policy, the sum of the first three terms on the right hand side of (V.12) is negative. This explains the ambiguity in the ranking of the optimal open-loop rule and the time-consistent policy in the case where there is uncertainty. The optimal open-loop rule is superior to the time-consistent policy insofar as it allows for the dependence of y_t on the anticipated future value of x_{t+1}. The time-consistent policy inappropriately treats y_t as given when the rule for x_{t+1} is chosen. The time-consistent policy on the other hand, being a feedback rule, permits a response of the instrument to new information. No open-loop rule permits such a response. The ranking of the two policies depends therefore on the numerical values of the parameters of the model and the objective function. The optimal time-inconsistent feedback rule dominates both the optimal open-loop rule and the time-consistent rule because it both allows for the dependence of the state on anticipated future instrument values and permits a response of the instruments to new information.

Conclusions

The single most important conclusion is that the case for conditionality in the design of policy rules has not been weakened by the "rational expectations revolution". This conclusion is uncontroversial for those policy instruments that are generally recognized as having real effects whether anticipated or unanticipated. Most fiscal instruments fall into this category. Even if there exist "pure stabilization" instruments -- monetary policy and changes in the (lump-sum) taxation-borrowing mix -- that are neutral when anticipated, known contingent rules may still affect real outcomes. This will be the case if feedback rules alter private forecast errors or influence revisions in private forecasts of future endogenous variables.

Time-inconsistency of optimal plans in non-causal models does not affect the superiority of conditional rules over open-loop rules.

The case against conditionality can therefore only be based on one or both of the following assumptions. First, that any form of conditionality in policy design introduces uncertainty about current and future policy instrument values that is absent under fixed rules. Second, that unconstrained by fixed rules, the authorities either pursue the wrong objectives or pursue the right objectives in an inept manner.

Footnotes

1/ In general, open-loop policies only require all present and future instrument values to be known at the beginning of the planning period. These known values need not, however, be constant.

2/ I assume for simplicity that there are no "delayed controls", i.e. x_t does not have to be chosen before t because it takes time to decide upon and realise a control action x_t. This assumption can be relaxed without altering any of the conclusions of this paper. See e.g. Deissenberg [1979, b].

3/ Any finite order vector autoregressive process in y_t with a random disturbance vector following any finite order ARIMA process can be rewritten in the first-order format given in (I.4). The state vector could also depend on a distributed lag in x_t; lagged x_t will in that case be included in the state vector y_t in (I.4). See Chow [1975].

4/ See Deissenberg [1979, b]. With measurement lags and imperfect state measurement, y_{t-1} in (I.5a) is replaced with its minimum variance prediction, given the information available at t. Kalman filtering is the standard technique for obtaining an estimate of y_{t-1} in the case in which some stochastic linear function of y_{t-1}, $\zeta_{t-1} = Dy_{t-1} + \varepsilon_{t-1}$ is observed when x_t is chosen rather than the true state y_{t-1}: (ε_t is a white noise random disturbance vector). See Chow [1975] and Deissenberg [1979, b].

5/ In essence, the optimal feedback rule specified x_t as a function of the best estimate, at t, of y_t. If neither y_t nor u_t are observable at t, $E(y_t|I_t) = A_t y_{t-1} + C_t x_t + b_t$. Assume some random function of y_t, $\zeta_t = Dy_t + \varepsilon_t$ is observable when x_t is chosen, in addition to exact information on y_{t-1}. D is a known matrix and ε_t a white noise disturbance vector. Then

$$E(y_t|I_t) = [I - MD][A_t y_{t-1} + C_t x_t + b_t] + M\zeta_t$$

$$M = [\Sigma_{uu} D' + \Sigma_{ue}][D\Sigma_{uu} D' + \Sigma_{ee} + D\Sigma_{ue} + \Sigma_{ue} D']^{-1}$$

$$\Sigma_{uu} = E(u_t u_t'); \quad \Sigma_{ee} = E(e_t e_t'); \quad \Sigma_{ue} = E(u_t e_t').$$

6/ Friedman made this point mainly with reference to monetary policy. See Friedman [1968].

7/ This intuitively obvious statement is made more precise in Barro [1976]. In his model, policy "surprises" increase the variance of real variables relative to their "full information" variances. i.e. their variances when the only uncertainty is irreducible, exogenous uncertainty. This will reduce welfare. Phelps [1978] considers optimal inflation policy in a model with adaptive inflation expectations. In such a model it is possible to trade off more employment today for more inflation tomorrow. Given a high enough discount rate, such a policy, which operates by fooling private agents into believing that the rate of inflation is less than it actually is, may appear to be optimal. This conclusion is somewhat suspect, as no costs are attached to the misinformation engineered by the monetary authorities.

8/ I offer no theory to explain this asymmetry in public and private opportunity sets; the argument solely concerns the consequences of such asymmetries, should they exist. Problems of moral hazard and adverse selection are probably behind the failure of many contingent forward markets to exist. The government's ability to tax (to exact unrequited transfers of wealth and income) and to declare some of its liabilities legal tender, and the associated difference in default risk between public and private sector bonds are likely to be sufficient to generate asymmetries in opportunity sets.

9/ That is, *open loop*, non-indexed, multi-period nominal wage and price contracts.

10/ Using the perhaps more acceptable specification of the employment equation $\ell_t = \min [\ell_t^d , \ell_t^s]$ adds complexity without affecting the main conclusion.

11/ We assume that the information set in period t includes all current and past observations of endogenous variables, policy instruments and random disturbances as well as the true structure of the model.

12/ Alternatively, the authorities could choose to completely eliminate the price forecast error $p_t - \hat{p}_{t|t-1}$, thus equating output to its *ex post* "natural" level, u_t^y.

13/ The delayed response of policy need not be due to an information disadvantage. It could also reflect a slower response by policy-makers to new information than by private agents due to "inside" policy lags.

14/ This neutrality result has two interpretations. 1) The comparison of two solution trajectories for all time with identical μ_t for all t but with the *level* of the money supply path higher by a constant fraction (in each period) for one of the paths. 2) The result of an unanticipated and immediately implemented once-and-for-all increase in the money supply, with the same percentage growth rates of money being maintained after the unanticipated money stock increase.

15/ A sequence of policy actions is time consistent if, for each time period, the policy action in that period maximizes the objective function, taking as given all previous policy actions and private agents' decisions and that all future policy actions will be similarly determined. (Kydland and Prescott [1977, p. 475]). This is Bellman's principle of optimality (Bellman [1957]).

16/ Note that if $k_3 = 0$, i.e. if no costs are attached to the policy instrument in period 1, the time-consistent policy is optimal in this simple example.

17/ by setting $u_1 = u_2 \equiv 0$.

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