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THE ROLE OF ECONOMIC POLICY AFTER THE NEW CLASSICAL MACROECONOMICS

Willem H. Buiter

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ABSTRACT

The paper considers the implications of the rational expectations New Classical Macroeconomics revolution for the "rules versus discretion" debate. The following issues are covered: 1) The ineffectiveness of anticipated stabilization policy, 2) Non-causal models and rational expectations, 3) Optimal control in non-causal models - the inconsistency of optimal plans. I established the robustness of the proposition that contingent (closed-loop or feedback) rules dominate fixed (open-loop) rules. The optimal contingent rule in non-causal models - the innovation or disturbance-contingent feedback rule - is quite different from the state-contingent feedback rule derived by dynamic stochastic programming.

Willem H. Buiter
Department of Economics
University of Bristol
40 Berkeley Square
Bristol BS8 1HY
ENGLAND

0272-24161, ext. 67

Summary

The paper considers the implications of the rational expectations - New Classical Macroeconomics revolution for the "rules versus discretion" debate. The following issues are covered 1) The ineffectiveness of anticipated stabilization policy, 2) Non-causal models and rational expectations, 3) optimal control in non-causal models -- the inconsistency of optimal plans. I establish the robustness of the proposition that contingent (closed-loop or feedback) rules dominate fixed (open-loop) rules. The optimal contingent rule in non-causal models - the innovation or disturbance-contingent feedback rule - is quite different from the state-contingent feedback rule derived by dynamic stochastic programming.[1]

1. *Introduction*

The stagflation of the past 15 years appears to have undermined conventional neo-Keynesian economics in the same way the Great Depression undermined neoclassical economics in the 1930's. The economic collapse of the thirties destroyed the faith of many in the self-regulating properties of the "unaided" decentralized market economy and motivated a major increase in the role of government in economic affairs. The worsening economic muddle of the late sixties and the seventies has seriously undermined neo-Keynesian optimism about the ability of government to select attractive combinations of output, employment, inflation and external balance through the judicious use of fiscal, monetary, financial and exchange rate policy. "Fine tuning," the sensitive response of monetary and fiscal instruments to even minor disturbances in economic activity, has acquired an especially bad name.

The skepticism about the ability of governments to use *stabilization policy* wisely has been matched by an increasingly vocal criticism of *structural policy*. By structura policies I mean policies that alter the level and composition of full employment output and employment, both in the short run - for a given capital stock and state of technology - and in the long run, when the size and composition of the capital stock and the state of technology are endogenous. *Stabilization policies* are policies that influence (and, one hopes, minimize) deviations of output and employment from their full employment ("natural" or "equilibrium") levels. The view advanced by Bacon and Eltis (1978) that the nonmarket sector has encroached unduly on the market sector represents a criticism of past and present structural policies. Policies aimed at altering the relative size of the public and private sectors or at changing a nation's consumption-investment mix are structural policies, as are policies designed to favor the primary, secondary or tertiary sectors. The Laffer curve is the conceptual foundation of structural tax policy proposals. Policies that influence the "natural" rate of unemployment (*e.g.* minimum wage laws) are structural policies.

If stabilization policies were defined to include only those policies that affect the fluctuations of output and employment around their "natural" levels without having any short-run or long-run effects on these "natural" levels themselves, the stabilization policy set would be the empty set. In virtually every macroeconomic or macroeconometric model that is not strictly for classroom use only, the distinction between the two kinds of policies is quite arbitrary. Certainly, every real-world economic policy action has both stabilization and structural consequences. This is, of course, quite consistent with ill-informed policymakers considering only either the stabilization, or the structural consequences of their actions and ignoring half the implications of their policies. Some of the most serious dilemmas in economic policymaking occur when a policy that is desirable for its short-run stabilization effects has undesirable long-run structural implications or vice versa. Cutting government spending to reduce demand pressures in an overheated economy may lead to painful changes in the composition of output away from the provision of public consumption goods or from investment in social overhead capital. A desire to reduce the (relative) size of the public sector may result in a slump when the cut in public spending is not immediately matched by an equivalent expansion of private domestic or external demand.

The practical impossibility of indentifying a pure stabilization policy that does not have any structural implications is of some importance when the policy conclusions of the New Classical Macroeconomics School are discussed below. A plausible interpretation of some of the writings of this school is that (at least) two pure stabilization policies exist. The first is monetary policy - the control of the nominal stock of high-powered money. The second is deficit financing - the substitution of borrowing (and sometimes also money financing) for lump-sum tax financing of a given level and composition of real exhaustive public spending. This view is incorrect: both these policies have structural consequences.

I consider the retreat from neo-Keynesian policy optimism both understandable and appropriate. In the light of the accumulated empirical evidence of the last 15 years some critical revaluation of the conventional wisdom of the fifties and the early sixties is clearly required. What is harder to understand is how, for so many, this retreat from the neo-Keynesian mainstream and from policy optimism has taken the form of a return to the neoclassical dogmas and modes of analysis that received such a battering in the thirties. The most convincing explanations for this curious phenomenon are the gradual passing of the generations whose consciousness was shaped during the Great Depression and the failure to teach economic history at all seriously in many contemporary graduate economics programs.

The revival of pre-thirties macroeconomics which is now widely referred to as the *New Classical Macroeconomics* is associated historically with Milton Friedman (1968) but has achieved its recent prominence as a result of the work of Edmund Phelps (1970), Robert Lucas (1972*a*, *b*, 1975, 1976), Thomas Sargent and Neil Wallace (1975, 1976), Robert Barro (1974, 1976, 1979), Edward Prescott (1975, 1977), Finn Kydland and Edward Prescott (1977), Bennett McCallum (1977, 1978), Robert Hall (1970, 1979), and a host of others. The major improvement of the modern variant over the original, as represented, *e.g.*, in the works of Hayek (1932, 1939), Knight (1941), Douglas (1932, 1935), Hawtrey (1926), Haberler (1932) and Fisher (1933), reflects the considerable progress made since the thirties in the technical aspects of economic analysis. We know now how to formally analyze simple, preferably linear, stochastic processes. A not entirely facetious characterization of the New Classical Macroeconomics is to regard it as a formalization of certain aspects of the old classical macroeconomics with white noise added. The new version compares unfavorably with the old one, however, in its unsophisticated treatment of the money supply process and of financial markets in general. The old classical macroeconomics was also more flexible in recognizing the possibility of departures from ideal competitive behavior in goods, factor and financial markets during cyclical upswings or downturns, although no formal characterization of such departures was ever provided.[2]

The New Classical Macroeconomics relies heavily on the application of the efficient markets hypothesis to all markets, real and financial. This means that prices in all markets are competitive, market-clearing prices that "fully reflect" all available information. They adjust instantaneously to current and anticipated future disturbances so as to balance notional demand and supply in each market. All agents are price takers. Households notional demands and supplies are derived from expected utility maximization subject only to the contraint of the household endowment valued at market prices that are viewed as parametric by each individual agent. The notional demands and supplies of firms are derived from market value maximization subject only to the constraint of the production possibility set, with all planned sales and purchases valued at prices that are viewed as parametric by each individual firm. Households and firms (and the government?) act as if, at the prevailing set of market prices, they can buy or sell any amount of any good or service. An industrious and costless auctioneer instantaneously and continuously sets prices in all markets at levels that make these notional demands and supplies mutually consistent.[3]

Compelling empirical evidence to support this extreme view of the way in which markets operate is seldom offered. This is not surprising, as it bears very little relation to the modus operandi of many labor, goods and financial markets in contemporary developed capitalist or mixed economies, as described in the labor economics, industrial organization and financial literature. Instead of carefu studies of market organization, a priori arguments are advanced that purport to identify privately rational behavior and the useful concept of equilibrium with Walrasian, competitive, market-clearing equilibrium. This "equilibrium approach" is then contrasted favorably with selected ad hoc neo-Keynesian approaches (Barro (I979), Lucas and Sargent (I978)).

The characterization of the New Classical Macroeconomics as *equilibrium economics* does not suffice to generate the New Classical invariance or policy neutrality propositions. It is also insufficiently precise because of the universality of the concept of equilibrium. *Equilibrium* refers to a state in which optimizing agents have no incentive to alter their behavior because, conditional on their expectations, their current plans are mutually consistent and can be executed. An *expectations equilibrium* is a slightly stronger concept, because it also requires that agents formulate plans or strategies on the basis of optimal inferences and forecasts of current and future exogenous and endogenous variables, that are consistent with the stochastic processes actually generating these variables. Until the constraints subject to which agents optimize, including their information sets, are specified, the assumption of equilibrium and optimizing behavior is essentially vacuous, because it does not impose refutable restrictions on observable behavior. The most general version of the Walrasian competitive equilibrium model represents only a very small move towards potential falsifiability: the equilibrium values of all real variables should be homogeneous of degree zero in all current and anticipated future money prices and nominal endowments, and Walras' Law should be satisfied.

One can have optimizing, privately rational behavior and equilibrium without this equilibrium being competitive. Monopolistic competition, oligopoly and monopoly are familiar market forms. More generally, game theory, and especially its dynamic extension, differential games, offers a wide variety of equilibrium concepts, many of which are more appropriate as approximations to actual market configurations than the Walrasian competitive equilibrium (Intriligator (I97I), Kydland, (I975), Bacharach (I976)). Even if a competitive equilibrium concept is preferred for certain markets, this competitive equilibrium need not be an efficient, Walrasian, market-clearing equilibrium.

Stiglitz *et.al.* have developed theories of nonmarket-clearing, quantity-constrained competitive equilibria for markets with costly, imperfect and asymmetric information (Stiglitz (1977, 1979), Grossman (1976), Grossman and Stiglitz (1976), Akerlof (1970), Riley (1979), Wilson (1977, 1979), Salop (1978, 1979) . For a somewhat different approach see Negishi (1960), Hahn (1979) and the recent survey by Drazen (1980)). Inefficient markets, *e.g.*, those characterized by a partial (or no) immediate response of prices to innovations in cost or demand, create opportunities for known monetary and deficit financing rules to have real effects (*e.g.* Buiter (1980*b*)). Noncompetitive game-theoretic equilibria and competitive but inefficient non-Walrasian equilibria will be the cornerstones of a "New Keynesian Macroeconomics." The Walrasian, efficient competitive market-clearing equilibrium remains a useful special case that may characterize a limited number of commodity markets and financial markets.

This paper analyses the implications of the New Classical Macroeconomics for the conduct of economic policy. The focus of the analysis is on what used to be called "rules versus discretion" but should be called fixed rules (rules without feedback or open-loop rules) versus flexible rules, *i.e.* rules with feedback, contingent rules or closed-loop rules. With open-loop policies the values of the actual time paths of the policy variables are specified at the beginning of a planning period and are functions only of the information available at the beginning of the planning period. These paths are not future information-dependent: they are to be followed by the policymaker without regard to future events or to any new information that may accrue as time passes. Milton Friedman's advocacy of a fixed growth rate for some monetary aggregate is an example of a very simple kind of open-loop rule. Closed-loop, contingent or feedback policies specify the values of the policy variables in period *t* as known functions of the information that will be available when a value will actually have to be assigned to the policy instruments, but may not yet be available in earlier periods. Thus future policy instruments are known functions of observations yet to be made. There is no serious disagreement that policy should be determined by rules. Views differ as regards the desirability of open-loop rules vis-a-vis closed-loop rules.

The application of stochastic dynamic programming to dynamic models in state-space form or 'causal' models leads to optimal contingent (feedback) rules that in models with uncertainty dominate any open-loop rule. In view of this, how can anyone argue that open-loop rules should be adopted? The common-sense reason for the superiority of contingent rules over fixed rules - that one can never do worse by permitting a flexible (but known) response to new information - seems robust.

There are three distinct foundations for the view that open-loop policies are superior to closed-loop rules. The first argument does not contest the proposition that monetary, fiscal and financial policies, anticipated and unanticipated, have important real effects, short run and/or long run. However, these effects come with lags that are often long and are always variable and uncertain. In such an environment, even a well-informed and well-intentioned policy maker is likely to have a difficult time determining the optimal feedback rule. Real-world governments are frequently neither well-informed nor well-intentioned. It is therefore preferable to constrain the policy authorities' options by committing them to simple fixed rules such as a constant growth rate for the money supply or a balanced budget - if necessary by constitutional amendment. This general position appears to be the one adopted by Milton Friedman. It reflects 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. Although I consider it to be the most powerful of the three arguments in favor of fixed rules, I shall not discuss it any further, as it ante-dates the New Classical Macroeconomics.

The second argument is that economic policy - mainly stabilization policy and often only monetary policy - is irrelevant for the behavior of the real economy to the extent that it is anticipated. Known, deterministic policy rules, open-loop or feedback, have no effect on the joint probability density functions of real economic variables. Applications of this view to monetary policy can be found in Sargent and Wallace (1975) and Barro (1976), who also applied it to deficit financing: the substitution of bond financing (and money financing?) for (lump-sum) tax financing of a real spending program has no real consequences (Barro (1974)).

McCallum (1977) argued that it held for all forms of stabilization policy. This second argument does not question the wisdom of attempts at stabilization policy, it questions the very possibility of stabilization policy. Since any known policy rule will have no real effects, the only contribution of the government to economic stabilization consists in not introducing additional uncertainty into the economy by having an unknown, stochastic policy rule. In principle any known feedback rule is as neutral as any known open-loop rule. In practice, however, instrument uncertainty is likely to be minimized by the selection of the simplest possible fixed rule. Some aspects of this second argument, that only unanticipated (stabilization) policy has real effects are analyzed in Section III alter a brief discussion of rational expectations in Section II.

The third argument 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 of the future.

Kydland and Prescott (1977) have shown that feedback rules derived by dynamic programming, which they call "consistent" policies, are sub-optimal in models with optimizing agents endowed with rational expectations of the future because such consistent policies fail to allow for the effect of anticipated future instrument values on current (and past) states. The optimal policy in such 'non-causal' models, they argue, is an open-loop rule.

To lay the groundwork for an analysis of this proposition, Section IV considers causal and non-causal solutions of dynamic systems and other non-uniqueness problems arising in models with rational expectations of future endogenous variables. Section IV then analyses the derivation of optimal policies in non-causal systems.

The conclusion reached by Kydland and Prescott that the consistent policy is suboptimal is confirmed. However, it is also shown that, in models with uncertainty, there always exists a feedback policy (called an "innovation-contingent" feedback policy) that dominates the optimal open-loop policy. Only in models without uncertainty is the optimal open-loop policy truly optimal.

I conclude that, with the exception of the demonstration of the inapplicability of traditional dynamic programming methods in non-causal models, the open-loop versus closed-loop debate stands where Milton Friedman left it. Further progress has to wait for the development of substantive economic models out of an emerging New Keynesian Macroeconomics.

II Rational Expectations

In the development of the New Classical Macroeconomics, rational expectations modelling has played an important part. It is however possible and in my opinion desirable to distinguish clearly between the insights gained from the rational expectations revolution per se and the contribution of the rest of the New Classical package. The other building blocks of the New Classical Macroeconomics - identical public and private sector opportunity sets or "Modigliani-Miller" of the public sector vis-a-vis the private sector, identical public and private information sets and efficient markets (see Buiter (I979*a*,*b*, (I980*a*,*b*), Buiter and Tobin (I979), Tobin and Buiter (I980)) - can be jettisoned without sacrificing the crucial contribution of the rational expectations revolution. This is the "principle of policy - dependent structural parameters" and its corrollary that in any model, New Classical or Old Keynesian, there is no scope for governments to use unanticipated policy in a systematic manner.

The expression "rational expectations" represents a minor abuse of language. Standard practice in economics commands that the label rational expectations be reserved for forecasts generated by a rational, *i.e.*, expected utility maximizing decision process in which the uncertain costs of acquiring, processing and interpreting additional information are balanced against the uncertain anticipated benefits from further refinement of the forecast. As used by the New Classical Macroeconomists, rational expectations shortcut the actual process of information gathering and forecasting and focus on the long-run equilibrium outcome of a "Bayesian" sequential prediction process, when forecasting has become a fairly simple and mechanical procedure: the subjective probability distribution of future economic variables held at time t coincides with the actual, objective conditional distribution based on the information assumed to be available at time t.[4] In many applications only the first moments of these distributions are assumed to be relevant. In Muth's original contribution, *e.g.*, (Muth (1961)), it was hypothesized that the mean expectation of firms with respect to some phenomenon *e.g.*, the future price of a commodity, was equal to the prediction that would be make by the relevant, correct and universally agreed upon economic theory. Future variables anticipated at time t are "true mathematical expectations of the future variables conditional on all variables in the model which are known to the public at time t" (Shiller (1978), p. 3). Analytical tractability often compels the use of linear models in which case rational expectations become least squares forecasts.

The specialization of rational expectations to best linear unbiased predictors conditional on an information set that includes the true, objective structure of the model is a powerful simplification that greatly facilitates practical applications. It also begs a number of crucial questions. The issue of how economic agents acquire their knowledge of the true structure of the economy which is used in making their rational forecasts is not addressed. The appeal of rational expectations lies in the fact that any forecasting scheme that is not rational in the sense of Muth will be consistently wrong: it will result in systematic, predictable forecast errors Sensible economic agents will detect unexploited arbitrage opportunities which will force the abandonment of the forecasting scheme and the adoption of a new one. Economic theory has very little to say about the learning process by which unsatisfactory forecasting schemes are revised. Ultimate convergence of the revision process to a rational expectations mechanism is neither self-evident nor inevitable (De Canio (1979)). Unless the forecasting mechanism has converged to the rational expectations scheme and economic agents know the true structure of the model, the crucial error-orthogonality property does not hold.[5] Analytical tractability is a necessary but not a sufficient condition for a model to be economically interesting. Since rational expectations is such a crucial assumption,[6] it would be most useful to have some direct tests of its validity. Unfortunately this behavioral hypothesis is seldom tested in isolation. Most applied econometric work incorporating the rational expectations hypothesis only permits the testing of composite hypotheses: natural rate of unemployment plus rational expectations, term structure of interest rates plus rational expectations, the market model of asset pricing plus rational expectations, international interest parity plus rational expectations, etc. Survey data, such as the Livingston price index, while subject to all the problems associated with measuring unobservables through questionnaires, provide direct test of such rational expectations implications as the error orthogonality property (see Brown and Maital (I979)). They have not been exploited to their full extent.

It is a commonplace that the behavior of private agents depends in many ways on estimates of imperfectly observed past and present variables and on expectations of future variables. If changes in public sector behavior alter these estimates and expectations, models that ignore links from (anticipated) government behavior via private expectations to private behavior are misspecified. Such misspecification may lead to poor conditional forecasts and to erroneous conclusions being drawn form policy evaluation using simulation methods.

The rational expectations approach offers a simple solution to the problem of the link between private sector behavior, private sector expectations and government behavior: the private sector is assumed to know the true structure of the model, including the parameters that describe government behavior. The lesson of the rational expectations view for macroeconomic and macroeconometric modeling is the requirement to solve simultaneously for the currently anticipated future value of an endogenous variable and its future value calculated from the model that incorporates these anticipations of the future. Once this is done the models include the response of the private sector to current and anticipated future government actions and fully respect the "principle of policy-dependent structural parameters." Policy simulations that are immune to the "Lucas Critique" can then be carried out.

III Real Effects of Anticipated and Unanticipated Money

In this Section of the Paper I discuss briefly some of the foundations and implications of the view that only unanticipated stabilization policy can have real effects. This proposition has been advanced seriously for only two kinds of policies: changes in the nominal supply of (outside) money balances and substitution of government borrowing for lump-sum taxation, keeping constant the size and composition of the government's real spending programme. The second one, "debt neutrality" has been dealt with at length in a number of recent papers (Barro (1974), (1978*a*), Buiter (1977, 1979*a*,*b*,*c*) Buiter and Tobin (1979), Tobin and Buiter (1980)). These demonstrated that the conditions for complete debt neutrality to hold are so extreme that they are certain to be violated in any real-world economy. Empirical attempts to quantify the degree of debt-neutrality have so far been completely inconclusive. In what follows attention is confined to the issue of the short-run and long-run neutrality of anticipated and unanticipated money.

Most channels through which changes in the nominal money stock can potentially affect real variables such as output and employment are represented in the "portmanteau" reduced form equation (1) which is a generalization of of an equation used in empirical work by Barro (1977*a*, 1978*b*) and Attfield, Demery and Duck (1979*a*,*b*).

$$\begin{aligned} y_t = Ax_t &+ \sum_{i=0}^{T_1} \sum_{j=0}^{S_1} b_{ij} \, [\dot{m}_{t-i} - E(\dot{m}_{t-i}/I_{t-i-j})] + \sum_{i=0}^{T_1} c_i \, \dot{m}_{t-i} \\ &+ \sum_{i=0}^{T_2} \sum_{j=0}^{S_2} d_{ij} \, E\,(\dot{m}_{t+i}/I_{t-j}) \qquad (1) \\ &+ \sum_{k=1}^{R_1} \sum_{i=-T_4}^{T_3} \sum_{j=0}^{S_3} e_{ijk} \, [E(\dot{m}_{t+i}/I_{t-j}) - E(\dot{m}_{t+i}/I_{t-j-k})] \\ &+ u_t \end{aligned}$$

For concreteness let y_t denote the logarithm of real output. x_t is a vector of regressors, possibly including lagged values of y_t, as well as those policy variables (public spending, tax rates) that are generally recognized to have real effects whether anticipated or unanticipated. These effects may of course differ with the extent to which the policies are anticipated and the degree to which they are perceived as transitory or permanent. $\dot{m}_t$ is the first difference of the logarithm of the nominal money supply. For our purposes it is not essential whether the levels or the rates of change of the money supply should be on the *r.h.s* of (1). u_t is an *i.i.d* random disturbance term.

Four kinds of channels through which money affects real variables can be distinguished

a) The inflation tax channel or *Tobin effect*. Anticipated future money growth, to the extent that it is associated with anticipated future inflation, will move desired portfolio composition away from assets that are poor hedges against inflation. *E.g.* in many money and growth models money and capital are the only two stores of value. With no market-determined interest rate attached to outside money balances, an increase in the anticipated future rate of inflation will reduce the demand for money, stimulate capital formation and thus over time boost productive capacity and actual output. Whenever output is a function of some anticipated real rate of return variable, either in the short run (via the supply of labour) or in the long run (via the capital stock), anticipated future money will have real effects unless money is super-neutral. This effect is captured by

$\sum_{i=0}^{T_2} \sum_{j=0}^{S_2} d_{ij} \; E(\dot{m}_{t+i}/I_{t-j})$. It has not been considered in the empirical work on anticipated and unanticipated money.

b) The multi-period non-contingent nominal contract channel or *Fischer-Phelps-Taylor effect*. One of the key assumptions required for anticipated monetary (and other) policy to have no real effects is that the private sector can respond to new information by changing all of its controls (labor supply, consumption, portfolio allocation, sales, etc.) at least as fast as the public sector can alter any of its controls. If the public sector can change at least one of its instruments (e.g., the money supply) continuously, while the private sector is locked into predetermined nominal contracts for finite periods, deterministic money supply rules will have real effects (Fischer (1977), Phelps and Taylor (1977), Taylor (1980) and Buiter and Jewitt (1980)). E.g., models incorporating overlapping multi-period nominal wage contracts exhibit very "Keynesian" behavior. In any given period, the majority of the labor force is covered by pre-existing nominal wage contracts. Each contract can in principle incorporate all relevant information on the behavior of the general price level and average wages over the life of the contract, that was available at the date the contract was entered into. It is not contingent on any new information that may become available over the life of the contract. As new information becomes available in period *t*, it is reflected only in the contracts that are up for renegotiation that period. The majority of the labor force is still covered by unexpired pre-existing contracts. Management responds to "innovations" in demand by altering output and employment at these precontracted wages. If the money supply can respond to demand innovations before each and every labor contract is up for renewal, output stabilizing monetary feedback rules exist. The *information sets* of the monetary authorities and the private sector may be identical, but the difference in *opportunity sets* - in this case in the speed of response to demand innovations - creates scope for beneficial or detrimental monetary feedback rules. The microfoundations of such multiperiod nominal wage contracts are still quite unsatisfactory (Barro (1977*b*, 1979)). In the U.S economy, at any rate, they are a fact of life and it seems unwise to deny their existence unless they can be fitted into an a prioristic paradigm of how the economy ought to work.

The Fischer-Phelps-Taylor effect is represented by

$\sum_{i=0}^{T_1} \sum_{j=0}^{S_1} b_{ij} [\dot{m}_{t-i} - E(\dot{m}_{t-i}/I_{t-i-j})]$ with $S_1 > 0$. In the empirical work of Barro et.al. referred to earlier, only current period (or one period ahead) forecast errors were included *i.e.* it was implicitly assumed that $b_{ij} = 0$ for $j > 0$. This precludes a search for the presence of Fischer-Phelps-Taylor effects. These require that current outputbe influenced by forecast errors from forecasts of money growth at a given date $(t-i)$ made at one or more dates before $t-i$; *i.e.*, at dates $t-i-j$ with $0 \leqslant j \leqslant S_1$

where S_1 represents the longest forecast horizon .

If monetary policy in period $t-i$ can be determined on the basis of information more recent than I_{t-i-S_1}, it can influence at least one monetary forecast error and thus real output.

c) The expectation revision channel or *Turnovsky-Weiss effect*. This effect is most easily demonstrated using the macro model of equations (2) and (3) which is a simplified version of a model of Turnovsky (1980).

$$m_t - P_t = \alpha_1 y_t - \alpha_2 [E(P_{t+1}/I_t) - P_t] + u_t^m \qquad \alpha_1, \alpha_2 > 0 \qquad (2)$$

$$y_t = \beta\, [P_t - E(P_t/I_{t-1})] + u_t^y \qquad \beta > 0 \qquad (3)$$

Equation (2) is a monetary equilibrium condition equating the real money supply to a Cagan-type demand for real money balances which is a function of real income and the expected future inflation rate. Equation (3) is a Sargent-Wallace (1975) supply function that makes output an increasing function of the gap between current price and last period's anticipation of the current price level. I_t includes current and past observations on y_t, P_t and m_t and the correct model of the economy as specified in (2) and (3). Assuming stability we can solve for the price forecast error as in (4).

$$P_t - E(P_t/I_{t-1}) = \frac{1}{1+\alpha_1\beta+\alpha_2}[m_t - E(m_t/I_{t-1})]$$

$$+ \frac{\alpha_2}{(1+\alpha_1\beta + \alpha_2)(1+\alpha_2)} \sum_{i=0}^{\infty} \left(\frac{\alpha_2}{1+\alpha_2}\right)^i [E(m_{t+1+j}/I_t) - E$$

$$(m_{t+1+j}/I_{t-1})] - \frac{1}{1+\alpha_1\beta + \alpha_2}(\alpha_1 u_t^y + u_t^m) \qquad (4)$$

Thus the current price forecast error is a function of the revision in the forecasts for all current and future money stocks between period t and $t-1$. Consider a monetary feedback rule that makes the current money supply a function of (in principle) all current and past disturbances.

$$m_t = \sum_{i=0}^{\infty} [\mu_{i,1} u^y_{t-i} + \mu_{i,2} u^m_{t-i}] \tag{5}$$

substituting this into (4) yields

$$\begin{aligned} P_t - E(P_t/I_{t-1}) = {} & \frac{1}{1+\alpha_1\beta+\alpha_2}(\mu_{0,1}u^y_t + \mu_{0,2}u^m_t) \quad (6) \\ & + \frac{\alpha_2}{(1+\alpha_1\beta+\alpha_2)(1+\alpha_2)} \sum_{i=0}^{\infty} \left(\frac{\alpha_2}{1+\alpha_2}\right)^i [\mu_{1+i,1}u^y_t + \mu_{1+i,2}u^m_t] \\ & - \frac{1}{1+\alpha_1\beta+\alpha_2}(\alpha_1 u^y_t + u^m_t) \end{aligned}$$

This shows that the government can completely eliminate the price forecast error $P_t - E(P_t/I_{t-1})$, either by responding only currently ($\mu_{1+i,1} = \mu_{1+i,2} = 0,\ i \geqslant 0,\ \mu_{0,1} = \alpha_1$ and $\mu_{0,2} = 1$)

or by responding currently and in the future or even by responding only in one or more future periods, to current disturbances. All that is required is that the $\mu_{1,i}$ and $\mu_{2,i}$ be chosen in such a way that

$$\mu_{0,1} + \frac{\alpha_2}{(1+\alpha_2)} \sum_{i=0}^{\infty} \left(\frac{\alpha_2}{1+\alpha_2}\right)^i \mu_{1+i,1} - \alpha_1 = 0 \tag{7a}$$

and

$$\mu_{0,2} + \frac{\alpha_2}{(1+\alpha_2)} \sum_{i=0}^{\infty} \left(\frac{\alpha_2}{1+\alpha_2}\right)^{i} \mu_{1+i,2} - 1 = 0 \qquad (7b)$$

E.g., if the government cannot respond currently to current disturbances (say, because unlike the private sector it receives this information with a one period lag) *i.e.* $\mu_{0,1} = \mu_{0,2} = 0$ and chooses to respond only with a one period lag, *i.e.* $\mu_{1+i,1} = \mu_{1+i,2} = 0,\ i \geqslant 1$, the price forecast error is eliminated by choosing and

$$\mu_{1,1} = \frac{\alpha_1(1+\alpha_2)}{\alpha_2} \qquad (8a)$$

$$\mu_{1,2} = \frac{1+\alpha_2}{\alpha_2} \qquad (8b)$$

Therefore, even if the government has information that is inferior to that available to the private sector, in the sense that it receives information on current and past realizations of random disturbances later than the private sector, it can eliminate the effects of current disturbances on the price forecast error from last period's forecast of the current price level (and therefore on the deviation of output from its ex-post "natural" level u_t^y). It does this by committing itself to respond in a known way to these current disturbances during some future period when the relevant information has become known to it.

This equivalence of current or instantaneous policy response and future or lagged policy response only holds when the current state of the system (p_t in our example) is a function of anticipations of future states ($E(p_{t+1}/I_t)$ in our example). Consider *e.g.* the case when $\mu_{i,1} = \mu_{i,2} = 0$ for all i except $\mu_{1,1}$ and $\mu_{1,2}$. Changes in m_t

in response to u^y_{t-1} and u^m_{t-1} have no effect on $P_t - E(P_t/I_{t-1})$ because u^y_{t-1} and u^m_{t-1} belong to I_{t-1}. Anticipated future changes in m_{t+1} in response to u^y_t and u^m_t, however, will effect the anticipated future price level $E(P_{t+1}/I_t)$ and thereby P_t and $P_t - E(P_t/I_{t-1})$.

Turnovsky has pointed out (Turnovsky (I980)) that the ability of lagged monetary feedback policy to affect real output will disappear if $E(P_{t+1}/I_t)$ in (2) is replaced by $E(P_{t+1}/I_{t-1})$. Unless the expectations in (2) and (3) are conditioned at different dates, new information accruing to private agents between periods $t-1$ and t cannot be reflected in the price level established in period t: both portfolio allocation decisions and money wage decisions for period t are predetermined from period $t-1$. Policy that depends for its effectiveness on the aquisition of new information by the private sector, on consequent expectation revision and on the immediate reflection of these new expectations in current prices will become powerless. Buiter and Eaton (I980) note that policy rules that operate through current (and/or past) expectations of future policy actions are time-inconsistent, an issue addressed in greater detail in Section 5.

If there are more independent targets than instruments or if the private secor does not have complete contemporaneous information on all disturbances, it will not be possible to achieve perfect stabilization, as we did in the simple example.[7] Nevertheless, the qualitative proposition that monetary policy effectiveness can be achieved via the effect of anticipated future policy remains valid (See Turnovsky (I980) and Weiss (I980)). This is one way in which rational expectations have increased the scope for stabilization policy beyond what is possible under ad-hoc expectations. The Turnovsky-Weiss effect is represented in (1) by

$$\sum_{k=1}^{R_1} \sum_{i=-T_4}^{T_3} \sum_{j=0}^{S_3} e_{ijk} [E(\dot{m}_{t+i}/I_{t-j})-E(\dot{m}_{t+i}/I_{t-j-k})]$$

It was not incorporated in any of the empirical work on anticipated and unanticipated money.

d) Other channels. The only term left in (1) is $\sum_{i=0}^{T_1} c_i \dot{m}_{t-i}$ representing past and present actual monetary growth. This can affect real output for a variety of reasons. The three major ones are money illusion, absence of debt neutrality in the presence of nominal interest-bearing public debt and ad-hoc sticky money wages or prices. The last category does not include those multi-period, non-contingent nominal contract models like Fischer (1977), Phelps and Taylor (1977), Taylor (1980) and Buiter and Jewitt (1980) that incorporate rational expectations and have all real variables homogeneous of degree zero in anticipated money, nominal wages and prices. These were discussed under the Fischer-Phelps-Taylor effect. The necessity of debt neutrality for neutrality of anticipated money is argued in Buiter (1979*a*,*b*; 1980*b*) and Tobin and Buiter (1980).

It is important in empirical work on equations such as (1) to incorporate the assumption of homogeneity of degree zero of all real variables in all actual and anticipated money prices and nominal quantitities. As a special case of this if there is debt neutrality, anticipated money should be neutral in the long run. The "Keynesian" proposition that anticipated money can have real effects in the short run is not to be confused with the strawman of long run money illusion (Gordon 1979).

IV Causal and Non-Causal Solutions to Rational Expectations Models and Other Non-Uniqueness Problems

Traditional optimal control techniques for dynamic models are presented most thoroughly in Chow (1975). In order to be applicable to problems encountered in modern macroeconomic analysis, the traditional approach must be extended in two directions. The first extension is to allow for many independent controllers or "players" with distinct and possibly conflicting objectives. Each player is aware of and responds to the current and anticipated future actions of the other players. Thus, instead of modeling a single controller playing a game against "nature," we need the approach of multiplayer dynamic game theory or differential games. This issue is considered in a longer version of this paper (Buiter (1980*a*)).

The second extension is to develop optimization techniques for noncausal models. Both single-player and many-player solution techniques need to be developed. The distinction between causal or backward-looking and noncausal or forward-looking models is a familiar one in the control engineering literature. In a causal system the state of the system at time τ, y_τ, is completely determined once a past state $y_{\tau-i}$, $i = 1,2, \ldots$ is given together with the entire sequence of values of the forcing variables or inputs, v_t, between $\tau-i+1$ and τ, i.e., $(v_{\tau-i+1}, v_{\tau-i+2}, \ldots, v_{\tau-1}, v_\tau)$. If the system is stable, the influence of the initial state will ultimately vanish and the current state will be a function only of all past and present inputs. Inputs are the exogenous variables, the instruments and the random disturbances. Causal system are solved forward in time from a given initial condition. Noncausal systems are systems for which it is not sufficient for determining y_τ to know an initial condition $y_{\tau-i}$, $i > 0$, and the values of the forcing variables or inputs between $\tau - i$ and τ(inclusive). In addition, knowledge of (expected) future inputs $v_{\tau+j}$, $j = 1,2, \ldots$, is required. Noncausal models have been argued to arise frequently in the context of rational expectations models, although some rational expectations models--those incorporating only current or past expectations of the present or the past--have generally been solved as causal models.

It is probably better to talk of causal and noncausal solutions to dynamic models than of causal and noncausal models. Every dynamic model, with or without rational expectations, has a causal (or "backward-looking") and a noncausal (or "forward-looking") solution. This is most easily demonstrated with the linear difference equation model of equation (9)

$$y_t = Ay_{t-1} + Cx_{t-1} \qquad (9)$$

y_t is a vector of state variables and x_t a vector of exogenous variables or policy instruments. The matrix A is assumed to be invertible. The causal or backward-looking solution y_t^b of (9) is

$$y_t^b = \sum_{k=0}^{\infty} A^k C x_{t-1-k} + \lim_{N\to\infty} A^N y_{t-N} \tag{10a}$$

The non-causal or forward looking solution y_t^f of (9) is

$$y_t^f = -\sum_{k=1}^{\infty} A^{-k} C x_{t-1+k} + \lim_{M\to\infty} A^{-M} y_{t+M} \tag{10b}$$

Indeed, as Blanchard (1978) has pointed out, any linear combination of the backward and the forward solutions with weights that sum to unity, such as y_t^m in (11), is also a solution to (9).

$$y_t^m = \alpha y_t^b + (1-\alpha)\, y_t^f \tag{11}$$

The mathematics are quite silent on which one of the continuum of solutions given in (11) to pick. Economic theory must narrow down the possible range. If y_t is an asset price determined in an efficient market the noncausal solution (10b) may be the natural one. In terms of equation (9), momentary equilibrium is represented by an equation relating the asset price, y_t, to its (actual and expected) future value y_{t+1} and an exogenous variable or policy instrument x_t. Such a noncausal solution was proposed by Sargent and Wallace (1973) for a money-and-growth model. If the price were determined in an inefficient market and is viewed as predetermined at any given instant, the causal solution is the appropriate one.

It is sometimes argued that the choice between the causal and the non-causal solutions should be based on the principle that unstable solutions are inadmissable. Note that if the model in (9) has a stable backward-looking solution for a constant path of the forcing variables ($x_t=x$), its forward-looking solution will be unstable and vice versa. If the characteristic roots of A are λ_i, $i=1,..,n$ the characteristic roots of A^{-1} are given by $\mu_i = \lambda_i^{-1}$.

There is of course nothing uniquely interesting about constant paths for the forcing variables. While they permit us to analyse the stability of the homogeneous equation system, the behaviour of the complete system cannot be determined until the actual trajectories for the forcing variables have been specified. Assume e.g. that all characteristic roots of A are unstable and that C is square and of full rank. Let x_t satisfy $x_t = C^{-1}(A^{-1}-A)y_t$. Equation (9) then evolves according to $y_t = A^{-1}\, y_{t-1}$. The causal solution is now stable and the non-causal solution is unstable.

If a random disturbance term u_t were added to equation (9), the causal solution would involve current and lagged disturbances and the non-causal solution actual, realized values of future random disturbances. While the mathematics are willing, economic sense does not accept the proposition that *actual* future realizations of random variables (as opposed to current and past estimates of future random variables or distribution functions of future random variables) can influence the current state. Non-causal models that arise in economic applications wil have known future deterministic exogenous variables and estimates of future random variables as determinants of the current state vector.

Some further non-uniqueness problems that arise in stochastic models with rational expectations of future endogenous variables can be illustrated with the simple Cagan-type hyperinflation model of equation (12)

$$m_t - p_t = -\alpha[E(p_{t+1}/I_t)] + u_t \qquad \alpha > 0 \qquad (12)$$

u_t is an *i.i.d.* random disturbance term. I_t, the information set conditioning expectations formed in period t, includes the market fundamentals (m_t, p_t the structure of the model, including the correct values of α and therefore u_t) as well as past values of m_t, p_t and u_t. It may also include current and past observations on an extraneous, "sunspot" variable ε_t which is an *i.i.d.* random disturbance.

The non-causal or forward-looking solution of (12) is :

$$p^f_t = \frac{1}{1+\alpha} m_t + \frac{1}{1+\alpha} \sum_{i=1}^{\infty} \left(\frac{\alpha}{1+\alpha}\right)^i E(m_{t+i}/I_t) - \frac{1}{1+\alpha} u_t \qquad (13)$$

$$+ \lim_{N \to \infty} \left(\frac{\alpha}{1+\alpha}\right)^M E(p^f_{t+M}/I_t)$$

The current price level is a function of the current money stock and the current "fundamental" disturbance u_t, all anticipated future money supplies and a transversality condition for

$\lim_{M \to \infty} \left(\frac{\alpha}{1+\alpha}\right)^M E(p^f_{t+M}/I_t) = \eta_t$. Even if we assume that

$\left|\frac{\alpha}{1+\alpha}\right| < 1$, η_t does not necessarily vanish. In fact any η_t that satisfies (14) can be substituted into (13)

$$\eta_t = \frac{\alpha}{1+\alpha} E(\eta_{t+1}/I_t) \qquad (14)$$

Consider e.g. the case in which η_t is an infinite distributed lag on the fundamental disturbance u_t and the extraneous disturbance ε_t.

$$\eta_t = \sum_{i=0}^{\infty} [\, a_i \, u_{t-i} + b_i \, \varepsilon_{t-i} \,] \qquad (15)$$

Let the a_i and b_i satisfy

$$a_i = \frac{\alpha}{1+\alpha} a_{i+1} \qquad i \geqslant 0 \tag{16a}$$

$$b_i = \frac{\alpha}{1+\alpha} b_{i+1} \qquad i \geqslant 0 \tag{16b}$$

The general non-causal solution to (12) is therefore given by

$$P^f_t = \frac{1}{1+\alpha} m_t + \frac{1}{1+\alpha} \sum_{i=1}^{\infty} \left(\frac{\alpha}{1+\alpha}\right)^i E(m_{t+i}/I_t) - \frac{1}{1+\alpha} u_t + \eta_t \tag{17}$$

where η_t is defined by (14) in general and, given our assumptions about I_t, by (15) and (16a,b). Note again that we cannot say anything about the stability of (17) until we have specified the stochastic process governing m_t.

Using the same kind of reasoning, the causal or backward-looking solution of (12) can be found to be

$$P^b_t = -\frac{1}{\alpha} \sum_{i=0}^{\infty} \left(\frac{1+\alpha}{\alpha}\right)^i m_{t-1-i} + \frac{1}{\alpha} \sum_{i=0}^{\infty} \left(\frac{1+\alpha}{\alpha}\right)^i u_{t-1-i} + \eta_t \tag{18}$$

η_t again satisfies (14), while a specific example of a process satisfying (14) and consistent with our assumptions about I_t is given in (15) and (16a,b). Note that even if $\left|\frac{1+\alpha}{\alpha}\right| > 1$, as will be the case if $\alpha > 0$, it makes no sense to describe (18) as unstable until the stochastic process governing m_t has been specified. For constant m_t, (18) is unstable if $\alpha > 0$, but with e.g.

$m_t = \left(\frac{1+2\alpha}{1+\alpha}\right) P_t$ this instability would be eliminated.

With the non-causal solution, an equal proportional increase in period *t* in the current and anticipated future money supplies raises the price level immediately and by the same proportion. By contrast, the causal solution shows that a fully anticipated increase in the money supply in period *t* will have no effect at all on the price level in period *t*; it will only affect the price level in period t+1 and beyond. Unanticipated current money, $m_t - E(m_t/I_{t-1})$, could be included in η_t and could therefore have an immediate effect on the price level. As it can enter η_t with a coefficient of either sign, the direction of the effect is arbitrary. Both (17), a "New Classical" equation and (18), an "Old Keynesian" equation are consistent with financial equilibrium and rational expectations. The policy implications of the two solutions differ greatly. By direct computation it can also be shown that linear combinations,with weights that sum to unity,of the causal and non-causal solutions are also solutions to (12).

Thus with rational expectations models that include current (or past) anticipations of future endogenous variables there are two kinds of non-uniqueness problems. As in all dynamic models, there is the problem of choosing between the causal solution, the non-causal solution and mixtures of the two. Additional information from outside the formal model is in general required to make this choice. The choice of the non-causal solution appears, on a priori economic grounds, to be appropriate for variables such as asset prices determined in efficient markets. In such models current asset prices are a function of expected future asset prices, and current prices can respond instantaneously to changes in information. For prices determined in inefficient markets the choice of the causal solution would seem to be appropriate. To rule out a solution because it is explosive for a constant path of the forcing variables is incorrect. First, there exist, in general, non-constant paths of the forcing variables that will stabilize a system whose homogeneous solution is unstable. Second, at any rate for causal systems, there is no good economic reason to rule out unstable solutions unless they lead in finite time to violations of physical or behavioural constraints. There is no divine guarantee that economic systems are stable.

In addition, having resolved this non-uniqueness problem, there is the problem of what to do about η_t in either solution. Unless one imposes the condition that $\eta_t \equiv 0$, "irrelevant" lagged fundamental disturbances and current and lagged extraneous random disturbances can enter the solutions (17) or (18). Price level variance minimizing solutions are characterized by $\eta_t \equiv 0$. For the η_t process in (15) this is achieved e.g. by setting $a_0 = b_0 = 0$. Whether decentralized markets can achieve the collectively rational decision of ignoring extraneous information and irrelevant lagged fundamental disturbances is an issue that has not yet been resolved. There may be a role for a central policy maker in imposing the minimum variance solution.

V Optimal Feedback Rules in Non-Causal Models: The "Innovation Contingent" Policy

In a well-known paper Kydland and Prescott have argued that optimal control in rational expectations models is impossible (Kydland and Prescott (1977)). In more recent statements, this argument has been weakened to the proposition that the search for optimal policies should be limited to a comparison of alternative fixed operating rules in order to select the one with the most attractive operating characteristics. The most plausible interpretation of their view is that in non-causal rational expectations models optimal policies are of the *open-loop* type rather than of the *closed-loop* or *feedback* type. As stated before, an open-loop policy is a non-state-dependent policy announced at some initial date which specifies the values of the policy instruments for all future time as a function of the information set at the initial date. Closed-loop or feedback policies make the values of the instruments at the current moment and in the future a possibly time-varying but known (as of the initial date) function of the current (respectively the future) states of the economy. These future states will be random variables in a stochastic world.

Kydland and Prescott's proposition is quite distinct from the New Classical proposition that only unanticipated (monetary) policy can have real effects. It applies with full force only if the anticipated future values of the policy instruments as well as innovations in the policy instruments affect the joint probability density functions of real variables. Traditional optimal control techniques such as stochastic dynamic programming do not allow for the impact of future policy measures on the current state through the changes in current behavior induced by anticipation of these future policy measures. Such "time-consistent" policies may be suboptimal. A time-consistent policy or plan is a sequence of rules, one for each period, which specifies policy actions contingent on the state of the world in that period. Each such rule has the property of being optimal given the subsequent elements of the sequence. (Prescott (I977)). In dynamic games with optimizing agents in which the current state depends on anticipated future states, the optimal plan in subsequent periods may not be the continuation of the first-period optimal plan over the remainder of the planning period: the optimal plan in a non-causal model may not be time-consistent.

In this section a linear-quadratic version of a simple two-period example due to Kydland and Prescott (I977) is analyzed that brings out the issues clearly. A deterministic model is considered first, followed by a stochastic version of the model.

A Certainty Model

The dynamic model is given in equations (19a,b,c), the objective function to be minimized in (20).

$$y_t = \alpha y_{t-1} + \gamma x_t + \delta x_{t+1} \qquad \alpha,\gamma,\delta \neq 0 \tag{19a}$$

$$y_0 = \bar{y}_o = 0 \tag{19b}$$

$$x_3 = \bar{x}_3 = 0 \tag{19c}$$

$$W = k_1(y_1 - a_1)^2 + k_2(y_2 - a_2)^2 + k_3(x_1 - a_3)^2 \qquad k_1,k_2,k_3 > 0 \tag{20}$$

The model is non-causal because the current state depends on a future instrument value. An initial condition for y_0 and a terminal condition for x_3 are needed to make this a well-defined problem.

The optimal policy can be derived by minimizing (20) with respect to x_1 and x_2 subject to the constraints (19a,b,c). This optimal solution is open-loop and time-inconsistent,that is, it does not take advantage of the "time structure" of the model by deriving, in each period, the optimal policy choice for that period as a function of the state at the beginning of that period, taking into account that the same optimizing approach will be adopted in all subsequent periods.

The optimal policy is:

$$x_1{}^* = \frac{\gamma^2 [a_1(\alpha\delta + \gamma) - a_2\delta] k_1 k_2 + a_3\delta^2 k_1 k_3 + a_3(\alpha\delta + \gamma)^2 k_2 k_3}{\gamma^4 k_1 k_2 + \delta^2 k_1 k_3 + (\alpha\delta + \gamma)^2 k_2 k_3} \tag{21a}$$

$$x_2{}^* = \frac{\gamma^3 [a_2 - \alpha a_1] k_1 k_2 + \delta [a_1 - \gamma a_3] k_1 k_3 + (\alpha\delta + \gamma) [a_2 - \alpha\gamma a_3] k_2 k_3}{\gamma^4 k_1 k_2 + \delta^2 k_1 k_3 + (\alpha\delta + \gamma)^2 k_2 k_3} \tag{21b}$$

The time-consistent solution, in the sense of Kydland and Prescott, is the solution derived by traditional dynamic programming methods that attempt to exploit the time structure of the model. Starting from period 2, the value function for the last period $\bar{\bar{W}}$ is minimized with respect to x_2, taking as given the values of y_1 and x_1. *I.e.*, the dependence of y_1 on x_2, modeled in equation (19a), is ignored. The "optimum" value of x_2, $\hat{x}_2$ is then substituted into $\bar{\bar{W}}$ to yield $\hat{\bar{\bar{W}}}$. The optimization problem for period 1 consists in selecting the value of x_1 that minimizes W, given that $x_2 = \hat{x}_2$. Thus the time-consistent policy for period 2 is derived by choosing x_2 to minimize $k_2(y_2 - a_2)^2$, treating y_1 as predetermined. This yields:

$$\hat{x}_2 = [a_2-\alpha y_1]\gamma^{-1} \qquad (22a)$$

Note that is implies $y_2 = a_2$.

The time-consistent policy for period 1 is derived by choosing x_1 to minimize

$k_1(y_1-a_1)^2 + k_3(x_1-a_3)^2$, given that x_2 is given by (22a).

This yields:

$$\hat{x}_1 = \frac{((\alpha\delta + \gamma)a_1 - \delta a_2)\gamma^2 k_1 + (\alpha\delta + \gamma)^2 a_3 k_3}{k_1\gamma^4 + k_3(\alpha\delta + \gamma)^2} \qquad (22b)$$

Using $\hat{x}_2 = [a_2-\alpha\gamma\hat{x}_1]\,[\alpha\delta + \gamma]^{-1}$, equation (22a) can be rewritten as:

$$\hat{x}_2 = \frac{(a_2-\alpha a_1)\gamma^3 k_1 + (a_2-\alpha\gamma a_3)(\alpha\delta + \gamma)k_3}{k_1\gamma^4 + k_3(\alpha\delta + \gamma)^2} \qquad (22a')$$

Comparing (21a) with (22b) and (21b) with (22a') we note that in a model without uncertainty the "time-consistent" policy is suboptimal and the optimal policy is time-inconsistent. This conclusion needs to be qualified in a major way when uncertainty is introduced.

A Stochastic Model

The stochastic version of the optimization problem given in equations (19a,b,c) and (20) is given below:

minimize $W = \min E[k_1(y_1-a_1)^2 + k_2(y_2-a_2)^2 + k_3(x_1-a_3)^2/I_1$

subject to:

$$y_t = \alpha y_{t-1} + \gamma x_t + \delta E(x_{t+1}/I_t) + u_t \qquad (23)$$

$$y_0 = \bar{y}_0 = 0$$

$$x_3 = \bar{x}_3 = 0$$

Without loss of generality we assume that I_t, the information set at the beginning of period t, does not contain y_t or u_t. When non-stochastic open-loop solutions are considered, $E(x_{t+1}/I_t) = x_{t+1}$. The optimal open-loop policy under uncertainty is the same as the optimal (open-loop) policy under certainty, given in (21a) and (21b). However, an open-loop policy cannot be truly optimal in a stochastic model. If $\alpha \neq 0$, y_t is a function of y_{t-1} (in our model y_2 is a function of y_1). When the optimal open-loop policy for periods 1 and 2 is chosen at the beginning of period 1,y_1 is unknown because it depends on the realization of the as yet unobserved disturbance u_1. After $t=1$, u_1 will be known. Any truly optimal policy rule for x_2 would enable it to respond to u_1. Conventional feedback policies that make x_t a function of y_{t-1} enable the policy instruments to respond to new information as it accrues. This advantage of feedback control in the presence of random disturbances has to be balanced against a disadvantage, highlighted in the certainty model: feedback control that makes x_t a function of y_{t-1} does not allow fully for the effect of future instrument values on the current state, both directly and indirectly through the effect of future instrument values on the optimal choice of current instrument values. Whether optimal open-loop control dominates or is dominated by feedback control can now only be determined on a case-by-case basis.

Note, however, that a more sophisticated kind of feedback control will not be subject to the Kydland-Prescott criticism. Optimal feedback control must permit a response of x_t to "news"; in our model this news consists of u_{t-1}, the random disturbance in the previous period. y_{t-1} is a function of $E(x_t/I_{t-1})$. To treat it as predetermined in the derivation of the "time-consistent" solution for x_t is suboptimal in almost all cases. u_{t-1} is not a function of x_t or $E(x_t/I_{t-1})$ but does convey useful information for the optimal choice of x_t. A truly optimal policy incorporates the dependence of y_{t-1} on x_t *and* allows a flexible response of future instrument values to future random disturbances. It can therefore be conveniently expressed as in "innovation" or "disturbance"-contingent policy. In a model with certainty the "innovation response" component of the optimal policy rule vanishes and the optimal rule is open-loop. Traditional time-consistent state-contingent feedback policies derived by dynamic programming may or may not be superior to the optimal open-loop policy, depending on the parameters of the model under consideration. There always exists an innovation-contingent feedback rule that is superior to the optimal open-loop policy. These points are illustrated with some simple examples.

The Time-Consistent or "State-Dependent" Feedback Policy

The time-consistent policy for period 2 is derived by choosing x_2 to minimize $E(k_2(y_2-a_2)^2/I_2)$,[9] treating y_1 as given. From the vantage point of period 2 we have $y_2 = \alpha y_1 + \gamma x_2 + u_2$. The solution for x_2 is:

$$\hat{x}_2 = [a_2-\alpha y_1]\gamma^{-1} \qquad (24a)$$

Note that this choice of x_2 implies that $E(y_2-a_2/I_2) = 0$. The time-consistent solution for x_1 is found by choosing x_1 to minimize $E(k_1(y_1-a_1)^2 + k_2(y_2-a_2)^2 + k_3(x_1-a_3)^2/I_1)$ given that x_2 is set according to (24a). This implies that $E(y_2-a_2/I_1) = 0$

The solution for x_1 is:

$$\hat{x}_1 = \frac{((\alpha\delta+\gamma)a_1-\delta a_2)\gamma^2 k_1 + (\alpha\delta+\gamma)^2 a_3 k_3}{k_1\gamma^4+k_3(\alpha\delta+\gamma)^2} \tag{24b}$$

Comparing (24a) and (24b) with (22a) and (22b) we note that the time-consistent solution is the same with and without uncertainty, provided the solution is expressed in feedback form. Under certainty, however, the time-consistent solution is suboptimal and the (time-inconsistent) optimal open-loop solution is the truly optimal solution. With uncertainty the expected loss under the optimal open-loop policy may either be smaller or larger than the expected loss under the time-consistent policy. This is because the optimal open-loop policy is not truly optimal because it cannot respond to future random disturbances. The optimal open-loop policy may be dominated not only by the time-consistent policy but also by simple ad-hoc (linear) feedback rules that permit future instrument values to respond to new information. The ranking of the various policies depends on all the parameters of the model under consideration and can only be established on a case-by-case basis.

To compare the expected loss under the optimal open-loop policy and the time-consistent policy we must evaluate

$E[k_1(y_1-a_1)^2 + k_2(y_2-a_2)^2 + k_3(x_1-a_3)^2|I_1]$ under the two regimes. Thus, for the open-loop policy we evaluate

$$\begin{aligned} W_u^* = E[&k_1(\gamma x_1^*+\delta x_2^*+u_1-a_1)^2 + k_2(\alpha\gamma x_1^*+(\alpha\delta+\gamma)x_2^*+\alpha u_1+u_2-a_2)^2 \\ &+ k_3(x_1^*-a_3)^2/I_1] \end{aligned} \tag{25a}$$

while for the time-consistent policy we evaluate

$$\begin{aligned} \hat{W}_u = E[&k_1(\gamma\hat{x}_1+\delta E(\hat{x}_2/I_1) + u_1-a_1)^2 + k_2(\alpha\gamma\hat{x}_1+\alpha\delta E(\hat{x}_2/I_1) \\ &+ \alpha u_1+\gamma\hat{x}_2+u_2-a_2)^2 + k_3(\hat{x}_1-a_3)^2/I_1] \end{aligned} \tag{25b}$$

Note that

$$E(\hat{x}_2/I_1) = [a_2-\alpha\gamma\hat{x}_1]\ (\alpha\delta+\gamma)^{-1} \tag{26a}$$

$$\begin{aligned}\hat{x}_2 &= a_2\gamma^{-1}-\alpha\hat{x}_1-\alpha\gamma^{-1}\delta E(\hat{x}_2/I_1) - \alpha\gamma^{-1}u_1\\ &= [a_2-\alpha\gamma\hat{x}_1](\alpha\delta+\gamma)^{-1}-\alpha\gamma^{-1}u_1.\end{aligned} \tag{26b}$$

To simplify the calculations, it is assumed that $a_1 = a_2 = 0$. As regards the random disturbances it is assumed that $E(u_1) = E(u_2) = E(u_1u_2) = 0$ and $E(u_1^2) = E(u_2^2) = \sigma_u^2$. Substituting (21a) and (21b) into (25a) and (25b), (26a) and (26b) into (25b) we obtain:

$$\begin{aligned}W_u^* = E[k_1&\left(\frac{a_3\gamma^2(\alpha\delta+\gamma)k_2k_3}{\gamma^4k_1k_2+\delta^2k_1k_3+(\alpha\delta+\gamma)^2k_2k_3}+u_1\right)^2\\ &+k_2\left(\frac{-a_3\delta\gamma^2k_1k_3}{\gamma^4k_1k_2+\delta^2k_1k_3+(\alpha\delta+\gamma)^2k_2k_3}+\alpha u_1+u_2\right)^2\\ &+k_3\left(\frac{-a_3\gamma^4k_1k_2}{\gamma^4k_1k_2+\delta^2k_1k_3+(\alpha\delta+\gamma)^2k_2k_3}\right)^2/I_1]\end{aligned}$$

$$\begin{aligned}\hat{W}_u = E[k_1&\left(\frac{a_3\gamma^2(\alpha\delta+\gamma)k_2k_3}{\gamma^4k_1k_2+(\alpha\delta+\gamma)^2k_2k_3}+u_1\right)^2\\ &+k_2(u_2)^2+k_3\left(\frac{-a_3\gamma^4k_1k_2}{\gamma^4k_1k_2+(\alpha\delta+\gamma)^2k_2k_3}\right)^2/I_1]\end{aligned}$$

Therefore,

$$W_u^*-\hat{W}_u = k_1[\left(\frac{a_3\gamma^2(\alpha\delta+\gamma)k_2k_3}{\gamma^4k_1k_2+\delta^2k_1k_3+(\alpha\delta+\gamma)^2k_2k_3}\right)^2 -$$

$$\left(\frac{a_3\gamma^2(\alpha\delta+\gamma)k_2k_3}{\gamma^4k_1k_2+(\alpha\delta+\gamma)^2k_2k_3}\right)^2] \tag{27}$$

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

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

Except for the term $k_2\ \alpha^2\sigma_u^2$, equation (27) also measures the difference between the loss under the optimal (open-loop) policy under certainty, W_c^* and the loss under the time-consistent policy in the case without uncertainty, $\hat{W}_c$. Therefore,

$$W_u^* - \hat{W}_u = W_c^* - \hat{W}_c + k_2\ \alpha^2\ \sigma_u^2 \tag{28}$$

In the absence of uncertainty we know that $W_c^* - \hat{W}_c < 0$.

With uncertainty however, it is quite possible that the minimum expected loss under the time-consistent policy is less than that under the optimal open-loop policy. A sufficiently large value of σ_u^2 will ensure this, if k_2 and α are not equal to zero.

An Innovation-Contingent Feedback Policy

It is easily established that the optimal open-loop policy given by x_1* and x_2* in (21a) and (21b) is dominated by an innovation-contingent feedback policy. Substituting the constraint given by (23) into the objective function yields:

$$W = E[k_1(\gamma x_1+\delta E(x_2/I_1)+u_1-a_1)^2+k_2(\alpha\gamma x_1+\alpha\delta E(x_2/I_1)+\gamma x_2+\alpha u_1 + u_2-a_2)^2 + k_3(x_1-a_3)^2/I_1] \tag{29}$$

Now the difference between x_2 and $E(x_2/I_1)$ can only be a linear function of the new information that has accrued between the beginning of period 1 when the expectation $E(x_2/I_1)$ was formed and the beginning of period 2 when x_2 is set (before y_2 and u_2 are observed). This new information consists only of u_1. We can therefore write:

$$x_2 = E(x_2/I_1) + Gu_1 \tag{30}$$

Here G is a linear function, to be chosen by the policy maker. Substituting (30) into (29) yields

$$W = E[k_1(\gamma x_1+\delta E(x_2/I_1) + u_1-a_1)^2 + k_2(\alpha\gamma x_1+(\alpha\delta+\gamma)E(x_2/I_1)+(\alpha+\gamma G)u_1-u_2-a_2)^2+k_3(x_1-a_3)^2/I_1] \tag{31}$$

We now minimize (31) with respect to x_1, $E(x_2/I_1)$ and G. This yields optimal values x_1^{**}, $E(x_2/I_1)^{**}$ and G^{**} given by

$$x_1^{**} = x_1^* \tag{32a}$$

$$E(x_2/I_1)^{**} = x_2^* \tag{32b}$$

$$G^{**} = -\alpha\gamma^{-1} \tag{32c}$$

The optimal innovation-contingent feedback policy is therefore given by:

$$x_1^{**} = x_1^{*} \tag{33a}$$

$$x_2^{**} = x_2^{*} - \alpha\gamma^{-1}u_1 \tag{33b}$$

The optimal innovation-contingent feedback policy has the optimal open-loop policy $(x_1{}^{*}, x_2{}^{*})$ as its open-loop component, that is, the component anticipated as of $t=1$. The optimal value of the feedback coefficient G is the one that exactly neutralizes the effect of u_1 on y_2.[10] The policy $(x_1{}^{**}, x_2{}^{**})$ dominates the optimal open-loop policy $x_1{}^{*}$, $x_2{}^{*}$, as can be seen by comparing W_u^{*} in (25a) with W_u^{**} below:[11]

$$W_u^{**} = E[k_1(\gamma x_1{}^{**}+\delta x_2{}^{**}+u_1-a_1)^2 + k_2(\alpha\gamma x_1{}^{**}+(\alpha\delta+\gamma)x_2{}^{*} + u_2-a_2)^2 + k_3(x_1^{*} - a_3)^2/I_1] \tag{34}$$

$$W_u^{*} - W_u^{**} = k_2\alpha^2\sigma_u^2 > 0 \tag{35}$$

The $(x_1{}^{**}, x_2{}^{**})$ policy is not "time-consistent" in the sense of Kydland and Prescott because it cannot be derived by the backward recursive optimization techniques of stochastic dynamic programming. It is therefore subject to all the well-known problems of inducing the policy-maker to adopt and stick with an optimal, time-inconsistent policy. This paper has nothing to say on how to adopt and enforce a time-inconsistent policy rule or "constitution". It does make clear that such a constitution should be a flexible, closed-loop constitution rather than a fixed, open-loop constitution. This is because $(x_1{}^{**}, x_2{}^{**})$ can only be specified as a feedback rule or contingent rule and because it dominates the time-inconsistent optimal open-loop rule except in the special case of no uncertainty, when the two policies coincide. It is easily checked that the innovation-contingent rule also dominates the time-consistent policy; from (35)

$$W_u^{**} = W_u^* - k_2\alpha^2\sigma_u^2 < \hat{W}_u$$

Conclusion

There has been a "rational expectations revolution" in macroeconomics. The subject will never be the same again. The "principle of policy-dependent structural parameters" brings out the need to model simultaneously the expectation formation process and the stochastic processes governing the behavior of the variables whose values are being predicted or inferred - stochastic processes that may themselves be functions of the expectation formation process. There is an urgent need to relax the extreme informational requirements of most current macroeconomic rational expectations models and to reformulate the rational expectations hypothesis in terms of a more general optimal Bayesian prediction and inference theory. Such developments are within reach and will in no way diminish the importance of the contribution of Lucas.

The rational expectations revolution has also forced a fundamental rethinking of the dynamic programming approach to optimization in dynamic economic models. In causal models, differential game theory provides the appropriate analytical tool for modeling the interdependence of rational private sector and public sector agents. (See Buiter (1980a)). In noncausal models, Kydland and Prescott's demonstration of the suboptimality of "consistent" plans derived from traditional dynamic programming approaches alters, but does not eliminate the scope for beneficial feedback policy. In models with uncertainty, the optimal open-loop policy need not dominate the "consistent" policy or other, ad-hoc feedback policies that make the values of the current policy instruments some known (linear) function of the information set at the time that the policy instrument value must be set. The optimal open-loop policy is dominated by the optimal linear innovation-contingent feedback rule that sets the current values of the policy instruments equal to their optimal open-loop values plus a linear function of the "news". There is no presumption that a suboptimal, restricted open-loop policy such as a constant growth rate for the stock of money will generate desirable outcomes in macroeconomic models that incorporate a variety of internal and external disturbances.

Acceptance of the importance of the contribution of the rational expectations hypothesis should, however, be kept quite separate from one's view on the value of the remainder of the New Classical Macroeconomics package. That remainder - the general application of the efficient markets hypothesis to goods and factor markets, the monetary neutrality and super-neutrality postulates, the debt neutrality theorem and the other assumptions underlying what I have called the "public sector-private sector Modigliani-Miller theorem" (Buiter (1979a,b) - does not constitute a promising approach to the analysis and control of real-world economic systems. The theoretical case against debt neutrality and against monetary superneutrality is overwhelming. A strong case also can be made for short-run real effects of deterministic money supply rules. The microeconomic foundations of inefficient markets are in the process of being developed. Non-cooperative game theory, bargaining theory and the theory of production and exchange under asymmetric, imperfect and costly information are the starting point for the New Keynesian Macroeconomics.

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FOOTNOTES

1. This paper was written while I was a consultant with the Financial Studies Division of the Research Department of the International Monetary Fund. The opinions expressed are my own. I would like to thank Mohsin Khan and Don Mathieson for discussions on causal and noncausal solutions to dynamic models, and George von Furstenberg for comments on an earlier draft. Sean Holly pointed out an error in an earlier version of the paper. An anonymous referee made extensive comm-

ents.

2. An excellent early survey of the role of monetary and real factors in the trade cycle is Haberler (1956). While emphasizing the importance of the money supply process and of financial factors in general, he also considers price and wage regidity to be necessary elements in the transmission mechanism. His emphasis on "large fixed monetary contracts" (p.139, p. 140) is also surprisingly "modern."

3. Price stickiness is consistent with only unanticipated policy having an effect on real output or employment as long as production and employment depend only on price surprises and not on the actual price. McCallum (1977, 1978) has sticky prices but equates the quantity produced to the notional supply of output which is a function of the price surprise only. One can even have a "disequilibrium" determination of production by assuming that actual output is the "min" of the effective demand for and the effective supply of output. As long as both effective demand and effective supply are functions of price surprises only, ineffectiveness of anticipated policy follows.

4. An early characterization of a "rational expectations equilibrium"can be found in Hayek (1939). "The main difficulty of the traditional approach is its complete abstraction from time. A concept of equilibrium which essentially was applicable only to an economic system conceived as timeless could not be of great value .... It has become clear that, instead of completely disregarding the time element, we must make very definite assumptions about the attitude of persons towards the future. *The assumptions of this kind which are implied in the concept of equilibrium are essentially that everybody foresees the future correctly and that this foresight includes not only the changes in the objective data but also the behavior of all the other people with whom he expects to perform economic transactions*" (Italics added).

5. This is the property that predictions of future variables differ from the actual future outcomes only by errors which are independent of the variables used to generate the predictions. Friedman (1979), p. 24

6. Crucial in the sense that major qualitative properties of the model depend on it.

7. Note that instead of minimizing deviations of output from the ex-post natural level u_t^y we could instead have minimized deviations of output from the ex-ante natural level, 0.

8. See also Taylor (1977), Aoki and Canzoneri (1979), Flood and Garber (1980).

9. Note that it is assumed that y_t and u_t are not elements of I_t. x_t has to be chosen before y_t and u_t are observed. This assumption can easily be relaxed to include partial or complete contemporaneous observations on y_t and u_t.

10. Having derived the optimal policy, x_2^{**} and x_1^{**}, we can, using (23), express the optimal value of x_2 as a function of y_1. While it is always possible to reformulate any innovation-contingent policy as a state-contingent one (and vice-versa), the innovation-contingent description of the optimal policy rule is preferable because it emphasises the nature of its derivation and the way in which it differs from the time-consistent policy.

11. In a private communication, Mr. C. R. Birchenhall of Manchester University has shown that the linear innovation contingent policy not only dominates the open-loop policy but also is the global optimal policy for this linear-quadratic model.