Money and Business Cycles: Comments on Bernanke and Related Literature

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Working Paper No. 49
July 1986

MONEY AND BUSINESS CYCLES:
COMMENTS ON BERNANKE AND RELATED LITERATURE

by

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Prepared for Carnegie-Rochester Conference on Public Policy (proceedings of the Fall 1985 conference). Comments by Marianne Baxter and Charles Plosser are gratefully acknowledged, but they should not be held responsible for any deficiences. Support from the NSF is acknowledged.

Ben Bernanke's paper on the alternative interpretations of the money-income correlations is an admirable piece of normal science in Kuhn's [1962] sense. It is a tribute to Bernanke and to macroeconomics more generally that a paper such as this can appear in the Carnegie-Rochester series on public policy. Bernanke is a researcher who has well developed ideas about the relationship between money and economic activity (see e.g., Bernanke [1983]), but this paper is not a pamphlet aimed at explaining his point of view to policymakers. Rather, it provides a description of alternative, competing explanations of nominal and real interactions, followed by empirical work aimed at distinguishing between these classes of models. The empirical work is conducted from a scientific perspective: Bernanke provides a battery of results for the reader, even though this precludes any fundamental resolution of scientific questions and no simple guidance for policy-makers.

My discussion of Bernanke's paper contains three elements. First, some alternative models of nominal and real interactions are considered. My attention is concentrated on two classes of equilibrium models of fluctuations because their dynamic implications have been well developed, the real business cycle analyses of Kydland and Prescott [1982] and Long and Plosser [1983] and the imperfect information monetary theories of Lucas [1972,1975] and Barro [1976].[1] In each case, the discussion focuses on implications that these models have for reduced forms (vector

[1] For the purposes of the present discussion, the imperfect information hypothesis is taken as initially presented in Lucas [1972] and Barro [1976], so that agents do not have information on the aggregate money stock, an alteration that is taken up in King [1981]. A potential rationalization of this restriction is provided by Edwards [1981], who argues that competitive equilibrium in the market for information will leave some fraction of agents incompletely informed about aggregate monetary conditions.

autoregressions), including contemporaneous and dynamic restrictions. Second, the econometric methodology that Bernanke uses to identify sources of shocks is considered--it is essentially a return to the Cowles Commission strategy (Hood and Koopmans [1953]), with its emphasis on contemporaneous interactions. Third, empirical results reported early in Bernanke's paper--largely consistent with those of other authors--would lead us to reject both the real business cycle and imperfect information versions of the macroeconomic models Bernanke considers, because their dynamic restrictions are inconsistent with observed time series. For this reason, some caution is necessary in interpreting Bernanke's analysis of the sources of shocks. In particular, Bernanke's measured shocks may not be economically relevant, but rather complex functions of the history of economically relevant shocks.

I. Modeling Nominal and Real Interactions

At present, there are four principal classes of economic models that concern the interaction between real and nominal variables: (i) real business cycle models, (ii) imperfect information equilibrium business cycle models, (iii) models with preset nominal prices that incorporate rational expectations and (iv) financial/credit theories of the cycle. My attention is restricted to the first two categories, because the dynamic implications of these models have been most fully developed, but my comments on methodology should apply to the other classes of models.

Real Business Cycle Models. In this ancient and honorable class of models, the study of the evolution of real variables (quantities and relative prices) is viewed as largely separable from nominal variables. Following Bernanke's notation, we can imagine a vector of real variables evolving according to a stochastic difference equation.

$$(1) \quad Y_t^r = \sum_{i=o}^{\ell} B_i^r Y_{t-i}^r + A^{rr} u_t^r$$

The focus of real business cycle theory to date has been on the propagation mechanisms (B_i, $i>0$) rather than on isolating specific impulses (u_t^r).

At this level, what does the real business cycle perspective have to say about the monetary sector? In their real business cycle model, Long and Plosser stress that shocks to specific sectors typically will be spread to other sectors when the shocked sector utilizes produced inputs. King and Plosser [1984] provide a model economy where there is a "banking sector" whose product (accounting services) is an input into final goods production, so that generally there will be a positive comovement of final goods production and banking sector production. That is, the A and B matrices are such that the population covariance between sector outputs is positive in the King and Plosser model.

However, macroeconomists are also interested in the interactions between nominal variables and real activity, which are not defined in the basic real business cycle models. An extension to the real business cycle model that makes predictions about nominal variables is provided by adding in a demand function for an external (fiat) money, a supply function for external money, and deriving asset pricing relations for nominal assets (e.g., the Fisher equation). (Such extensions are undertaken in King and Plosser [1984] and Eichenbaum and Singleton [1986]. The former authors take a conventional macroeconomic approach, viewing the real subsystem (1) as invariant to the introduction of factors giving rise to a demand for external money. The latter authors provide a general equilibrium, cash-in-advance model in which this separation is invalid).

These additional elements imply that one adds on a vector of nominal variables to the above, including the price level, nominal external money stock and nominal interest rate, so that the overall system becomes

$$(2)\ Y_t = \sum_{i=o}^{\ell} B_i Y_{t-i} + A u_t,$$

where the overall vector Y contains real variables considered earlier (Y^r), nominal variables, and (under rational expectations) any other variables to which monetary policy systematically responds since these will affect expected inflation. The exact form of the A and B_o matrices depend on the form of the money supply rule, etc. in ways that are nicely laid out in Bernanke's analysis. But, in any event, there are a large number of zero restrictions built into the model by the assumption that the propagation mechanisms are entirely real. That is, the matrices B_i corresponding to lagged Y (i>0) have the form

$$B_i = \begin{bmatrix} B_i^{rr} & B_i^{rn} \\ B_i^{nr} & B_i^{nn} \end{bmatrix}$$

with all elements of B_i^{rn} equal to zero. This restriction reflects the fact that agents care only about lagged variables because they capture the "state of the economy" and that the propagation mechanisms are completely real.

Incomplete Information Equilibrium Models. The class of business cycle models developed by Lucas [1972, 1975] and Barro [1976] is basically identical to the real business cycle models with one central exception. Because agents have incomplete information with respect to aggregate variables within a given period, the form of the contemporaneous interactions (B_0) and A are such that the neutrality implications of certain shocks are altered from the real business cycle model. That is, in the real business cycle model above, shocks to the supply and demand for external money had no effect on the real subsystem (1), but under the Lucas-Barro story these have real effects within a decision period. However, the assumption of incomplete information models is typically that the real dynamics in subsystem (1) are unaltered, as these simply involve the influence of capitalistic production. (Sargent [1979] provides a nicely worked out linear-quadratic model that displays this property).

II. Implications for Reduced Forms

With these two classes of models in hand, we can inquire about the sorts of restrictions that each places on the data. Because there is a dynamic dichotomy in system (2), in that the past history of nominal variables does not enter in subsystem (1), the real business cycle and imperfect information models share an implication for tests of block Granger causality within unrestricted reduced forms (vector autoregressions), as first pointed out by Sims [1980]. In particular, the real variables in (1) should not be Granger-caused (predicted) by the additional nominal variables in (2).

Bernanke's table 1 provides some evidence on this issue--the log level of real output is predicted by the narrow money stock (M1) at the 1 percent marginal significance level and by the monetary base (B) at the 10 percent level. The theory above involves multivariate relations; real activity as a block should not be Granger-caused by nominal variables as a block. Appropriate multivariate tests have been performed by Sims [1980], Litterman and Weiss [1985], and Eichenbaum and Singleton [1986]; the former two papers report results that are not supportive of the theory; the results of the latter paper are more mixed.[2]

But there are some difficulties in using Granger causality tests to determine the adequacy of equilibrium business cycle models. As Sargent [1979] has shown, if there is serial correlation in the (exogenous) real components of (2), then the incomplete information models do not predict that there will be an absence of Granger causality. The basic point is that the incomplete information model predicts that lagged nominal shocks have no real effects given the relevant history of the economy (certain lagged quantity measures representing capital of various sorts and exogenous serially correlated real forcing variables). However, it is not necessarily possible to test for this model implication with a simple application of Granger causality tests, since these are an implication of the model only if the real exogenous variables are serially uncorrelated. The difficulty can be illustrated in the following model. Let y be output and m be the money stock. Then,

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[2] These empirical analyses differ in a number of ways, including lists of real and nominal variables considered. Working with a specific variable list, Eichenbaum and Singleton show that the maintained hypothesis on the trend stationarity or differenced stationarity of the time series can have a substantial effect on Granger tests. Nelson and Plosser [1982] provide evidence that one cannot reject the differenced stationary representation of a large number of time series, including real output and nominal money stocks.

$$(3a) \quad y_t = \alpha\,(m_t - Em_t | I_{t-1}) + \lambda\, y_{t-1} + \eta_t$$

$$(3b) \quad \eta_t = \rho\, \eta_{t-1} + \nu_t$$

$$(3c) \quad m_t = \mu\, m_{t-1} + \chi\, y_{t-1} + x_t$$

define a system which combines real propagation mechanisms with the temporary noneutrality of the sort suggested by Lucas and Barro. Let us begin by considering this system under the initial assumption that $\rho = 0$, so that there are serially uncorrelated real disturbances. In this situation, as the expectation error concerning money is uncorrelated with all information at t-1. Thus, the expectation even is uncorrelated with lagged money, according to the model. Then, the distributed lag regression (4) should have zero coefficients on lagged money.

$$(4) \quad y_t = \lambda\, y_{t-1} + \sum_{i=1}^{\infty} \beta_i\, m_{t-i} + \nu_t,$$

That is, according to the theory all of the β_i should be zero in (4). However, if ρ is nonzero in equation (3a), but satisfies the stationarity requirement (the absolute value of ρ is less than one), then it follows that

$$(5) \quad y_t = \lambda\, y_{t-1} + \rho\lambda\, y_{t-2} + \alpha\rho(m_{t-1} - Em_{t-1} | I_{t-2}) + \{\alpha\,(m_t - Em_t | I_{t-1}) + \nu_t\}\ .$$

Thus, a lagged expectation error concerning money enters in the output equation given past output.[3] In turn, output will be related to the level of m_{t-1} and m_{t-2} since $Em_{t-1}|I_{t-2} = \mu_1 m_{t-2} + \chi y_{t-2}$. Thus, in general, the Granger causality test fail despite the fact that the model is constructed to display neutrality for rationally expected movements in money. However, if one is willing to specify the autoregressive structure for the exogenous variable (η_t), then one can construct a valid test through cross equation restrictions (McCallum (1979)). But, to my knowledge, such procedures have not been employed, perhaps because they run counter to Sims' [1980] view that identification via specification of stochastic processes on disturbances is "incredible."

An analagous pitfall is encountered in the application of Granger-causality tests to real business cycle models. Since these models can be viewed as a special case of the Lucas-Barro model with zero temporary nonneutrality ($\alpha = 0$), one might infer from (5) that real business cycle

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[3] If the serial correlations in the errors is a moving average process, the difficulties become even worse, since the autoregressive representation is infinite order. To see this, suppose that we replace (3b) with

$$(3b)' \quad \eta_t = \nu_t - \theta \nu_{t-1}$$

and impose the invertibility requirement that $|\theta|<1$. Then, the expression corresponding to (5) becomes

$$(5)' \quad y_t = (\lambda-\theta) \sum_{i=o}^{\infty} \theta^i y_{t-i} + \alpha \sum_{i=o}^{\infty} \theta^i (m_{t-i} - Em_{t-i}|I_{t-i-1}) + \nu_t.$$

That is, there is no hope of executing a modified Granger test by lagging the information set when there are moving average errors.

models can readily be rejected by Granger causality tests.[4] But a similar counterexample can be constructed that cautions us against regarding Granger causality tests conducted on one set of variables as providing information about real business cycle models more generally.[5] The key point in the previous counterexample was that the relevant state of the economy for private sector decision-makers was the vector (y_{t-1}, η_{t-1}), but the econometrician mistakenly viewed it as the history of the output series (y_{t-s} for all $s > 0$). In the present context, suppose that the relevant state of the economy is given by the (2x1) vector $s_t = (s_t^1, s_t^2)'$ and that the linear real business cycle model specifies that

$$(6a) \quad y_t = \omega_1 s_{t-1}^1 + \omega_2 s_{t-1}^2$$

$$(6b) \quad s_t = \Lambda s_{t-1} + \nu_t$$

$$(6c) \quad m_t = \mu_1 s_{t-1}^1 + \mu_2 s_{t-1}^2,$$

where Λ is a 2x2 matrix of coefficients governing the (exogenous) dynamics of the state vector and ν_t is a (2x1) vector of shocks. Write the vector of variables that are observable to the econometrician as

$$(7) \quad \begin{bmatrix} y_t \\ m_t \end{bmatrix} = W s_{t-1} = \begin{bmatrix} \omega_1 & \omega_2 \\ \mu_1 & \mu_2 \end{bmatrix} \begin{bmatrix} s_{t-1}^1 \\ s_{t-1}^2 \end{bmatrix} .$$

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[4] McCallum [1986] entertains this view in interpreting some empirical results of Litterman and Weiss [1985].

[5] The next two examples draw heavily on one constructed by Marianne Baxter.

Then, it follows that the observable $z = (y,m)'$ vector can be written as

$$(8) \quad z_{t+1} = \Lambda W^{-1} z_t + \nu_t.$$

In general, then, the monetary variable m appears to predict the real variable y because the econometrician has not specified the state vector adequately, which is the same element which is central to the prior example.

In general, when the researcher has not accurately captured the state of the economy relevant to private sector decision-makers, the innovations to an empirical vector autoregression also do not correspond to the shocks that one would seek to isolate in an investigation of the source of economic fluctuations. In the example of equations (3)-(8), the (y,m) (first order) vector autoregression retrieves the shocks to the vector $s = (s^1, s^2)'$ vector and attributes them to the (y m) vector. Thus, measured monetary shocks appear to cause real activity even when (i) the business cycle is entirely real, (ii) there are no contemporaneous interactions between variables (simultaneous equations problems); and (iii) when there are no true monetary shocks. The vector autoregression procedure (equation (8)) does retrieve a set of shocks (ν_t) that are truly surprises from the standpoint of economic agents.[6] But this implication does not carry over in models where there are additional error terms in (6a, c), so that there is not an exact relation between (y, m) and (s^1, s^2). To see this, consider an extended example where there are monetary shocks that potentially have real effects.

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[6]Note, however, from (8) that one would misdate the shocks by one period, since the ν_t appear as innovations to the (y, m) vector at date t+1.

$$(9a)\quad y_t = \omega_1 s^1_{t-1} + \omega_2 s^2_{t-1} + \alpha x_t$$

$$(9b)\quad s_t = \Lambda s_{t-1} + \nu_t$$

$$(9c)\quad m_t = \mu_1 s^1_{t-1} + \mu_2 s^2_{t-1} + x_t$$

Then, the kth order vector autoregression for the observed $z = (y,m)$ vector takes the form, $B_k(L)\, z_t = \epsilon_t$, where the coefficients in the $B_k(L)$ polynomial are chosen according to the least squares filtering formulae given by Whittle [1963]. Let the moving average representation of $z = (y,m)$ in terms of the fundamental innovations be

$$(10)\quad z_t = [I - \Lambda L]^{-1}\, \nu_t + \underline{\alpha}\, x_t = \sum_{i=1}^{\infty} \Lambda^{i-1}\, \nu_{t-i} + \underline{\alpha}\, x_t,$$

where the vector $\underline{\alpha}$ is $(\alpha\ 1)'$. Then, the relationship between the measured innovations and the fundamental shocks is

$$(11)\quad \epsilon_t = B_k(L) z_t = B_k(L)[I - \Lambda L]^{-1}\, \nu_t + B_k(L)\underline{\alpha}\, x_t$$

Thus, the measured shocks are long moving averages of the fundamental shocks.

What is the list of state variables in the real business cycle models of Kydland and Prescott [1982] and Long and Plosser [1983]? In the Kydland and Prescott setup, there is a completed capital stock, a distributed lag of leisure, uncompleted capital goods (due to the time-to-build technology) and the technology shock (which follows a Markov process). In the Long and

Plosser multiple sector setup, the state variable is the complete vector of sectoral outputs and a vector of sectoral technology shocks (a vector Markov process). Empirical researchers such as Sims [1980] and Litterman-Weiss [1985] have utilized vectors of variables that do not capture the relevant state of the economy in the theories of Kydland-Prescott and Long-Plosser. Thus, one cannot make inferences about the validity of these theoretical models from Granger causality tests reported by these empirical researchers. In general, such tests seem most valuable as part of an investigation of a particular model (or small class of related models) so that there is an explicit framework for determining the relevant state vector.

III. Bernanke's Empirical Analysis

In his analysis of alternative theories of business fluctuations, Bernanke adopts the following procedure. First, he identifies a list of macroeconomic variables that play a central role in a particular class of theoretical models. Second, he considers those variables as evolving according to an vector autoregression. Third, he considers the restrictions that a particular class of theories place on contemporaneous interactions (the A and B_0 matrices above), restricting these in a sufficiently tight manner so that there are at most the number of parameters in the theoretical structure than in the contemporaneous covariance matrix of vector autoregression residuals, assuring identification of these behavioral parameters. To implement this approach empirically, Bernanke estimates a vector autoregression, with the order (overall lag length) taken to be sufficiently large that marginal lags add little to the fit of the model.

Finally, the behavioral parameters are estimated from the residual covariance matrix of this vector autoregression.

Thus, Bernanke's procedure emphasizes contemporaneous interactions between economic variables, in contrast to the forgoing dicussion which stressed dynamic interrelationships while downplaying the contemporaneous interactions. In my view, by spelling out contemporaneous interactions, Bernanke is pursuing a strategy that is necessary to gain additional knowledge about sources of shocks; my emphasis on dynamic relations between variables should not be taken to mean that there is disagreement between us with respect to this issue of methodology.[7]

But although specification of contemporaneous interactions is necessary, it does not strike me as sufficient. That is, the examples of the previous section have implications for interpreting for Bernanke's empirical work. In pursuing this consideration, it is assumed that multivariate tests of predictive content of nominal for real variables in Bernanke's system would sustain the results in Bernanke's table 1, i.e., nominal variables would continue to Granger cause real variables when the causality tests were undertaken in a multivariate manner. In turn, this would rule out the simplest equilibrium business cycle interpretation — with or without temporary real effects of monetary shocks — of Bernanke's variables.

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[7]Bernanke follows earlier work by Hall [1978] and Blanchard and Watson [1984] to investigate the sources of shocks, by specifying economic models of the contemporaneous interactions between economic variables, which is a return to the scientific discipline imposed by the Cowles Commission style of econometrics. Cooley and Leroy [1985] have recently marshalled convincing arguments that one can meaningfully interpret vector autoregressions only in the context of this strategy. Specifically, it is only in the context of a structural model that one can meaningfully undertake the examination of moving average representations and variance decompositions that one associates with Sims [1980].

From the examples of section II, this could arise for one of two reasons (i) because there is not a sufficiently rich empirical state vector <u>or</u> (ii) because predictable variations in nominal variable are relevant for the evolution of real activity. This raises two questions:

How important is it that we choose between these alternative interpretations? The examples of the previous section suggest that it is essential. In the Sargent example, given by expressions (3), Bernanke's empirical procedure would correctly isolate an economically relevant set of innovations, with the dynamic dichotomy being rejected by Granger causality tests. There would be substantial interest in moving average representations and variance decompositions, for these would tell us about the dynamic effect of monetary shocks on real activity and the fraction of cyclical volatility of output accounted for by such shocks. In the second example, given by expressions (9), Bernanke's procedure would calculate measured innovations that would be meaningless, mongrel combinations of the history of all economically relevant innovations. Consequently, it could plausibly be the case that the examination of Bernanke's moving average representations and variance decompositions are not relevant to our understanding of business cycles. Thus, it is essential that we determine which of these explanations for failure of dynamic implications of theory is operative.

How might we choose between these alternative interpretations? My own sense is that some measure of the phenomena isolated by the second example must be operative in Bernanke's empirical analysis because the relevant state of the economy in prominent equilibrium theories--such as that of Kydland and Prescott--is not captured by the model's variables. But I would be convinced that the first example was operative if the model passed rational expectations econometrics tests for dyanamic interactions, specifically the (cross equation) restrictions implied by the presence of unanticipated money in (5).

Since most of Bernanke's discussion of econometric methodology and empirical work takes as given that the dynamics of the model are not inconsistent with the data, it is presumably best to view these as illustrative of what one _might_ do with a business cycle model whose dynamic implications are _not_ rejected.

Conclusions

The development of additional tested knowledge about the cyclical relationship between money and business cycles can follow from additional empirical work that follows Bernanke's path, if additional attention is paid to validation of models of economic dynamics. In this process, it may be that real business cycles--narrowly intepreted as a hypothesis about the sources of shocks to the macroeconomy--will fall victim to the data. But the virtue of real business cycle analysis is that it provides a vehicle for thinking clearly about the economic mechanisms that govern the dynamics of economic time series. Since isolation of these mechanisms is a necessary precondition for investigating the sources of shocks, in my view, then the approach taken by the real business cycle program will be an integral part of empirical and theoretical research in macroeconomics over the forseeable future.

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