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MODELS AND THEIR USES

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ABSTRACT

It is argued that economists ought to recognize that modeling in different styles will be appropriate for different purposes or different stages in the development of an area of economics. As an example, the paper displays simulations of a stochastic general equilibrium model which shed light on the interpretation of widely discussed small macroeconomic vector autoregressive models connecting monetary variables to output and prices.

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Models and Their Uses

I. Introduction

There are economists doing research with VAR models or other kinds of lists of regression equations with little or no formal behavioral theory. There are economists studying purely theoretical models, apparently unembarrassed that the models' connections to any observable phenomenon are at best tenuous. In between we have structural VAR modelers (like Orden and Fackler in this session, or Blanchard and Watson, Bernanke, or myself [1986]), who give formal partial behavioral interpretations to statistically detailed models and calibrators (like Kydland and Prescott or Gary Hansen) who use complete behavioral models but match them to only a few aspects of the data, without any formal statistical methodology.

This is as it should be, more or less. We should not expect our discipline to be exempt from the pattern of the natural sciences, in which models of different types and levels of detail are used for different purposes. Many, maybe even most, practical applications of the laws of natural science ignore the "microfoundations" of quantum and relativity theory. In applications like weather forecasting or epidemiology, detailed use of data often requires modeling with little explicit guidance from physical theory. And on the other hand cosmologists theorize with about as little concern for connecting their theories to something observable as the more abstract mathematical economists.

It is dismaying, therefore, that as we economists begin to use an increasingly differentiated array of model types, we seem to be dissipating energy in argument over what kind of modeling style is correct. As someone who is more easily bored by empty theory than by raw data, I have the possibly biased impression that most of this energy comes from the side of more "structural" researchers attempting to cleanse the profession of what they see as meaningless exercises in measurement without theory. Countless articles and seminars begin with a brief paean to the virtues of guiding empirical work by explicit theory, or of the value of theory as "discipline" for empirical work. It may even be a verifiable regularity that this kind of introductory remark is an indicator that the research that is about to be described contains a particularly outrageous simplifying assumption in the theoretical model, justifiable only under the hypothesis that <u>some</u> formal theory, however implausible, is better than the informal theory that might otherwise be used to interpret the data.

VAR modelers ought to admit, as I certainly do, that an ideal model which: i) contains a fully explicit formal behavioral interpretation of all parameters; ii) connects to the data in detail; iii) takes account of the range of uncertainty about the behavioral hypotheses invoked, and iv) includes a believable probability model that can be used to evaluate the plausibility, given the data, of various behavioral interpretations; is better than the usual nonstructural VAR model. Correspondingly, modelers who match their models only to a few "stylized facts" or a few contemporaneous second moment statistics ought to admit that such an ideal model would be preferable to the models they use. The problem is that ideal models take up human and computer time, so that every actual model is a compromise. Depending on the problem at hand and the skills and inclinations of the researcher, there may be valuable modeling efforts which leave to informal common sense the question of connection to data, just as there may be valuable efforts which leave to informal common sense the question of how patterns found in the data, say computed MAR impulse responses, connect to a behavioral interpretation.

Though my usual inclination is to defend careful statistical work against the onslaughts of the smug "no measurement without theory" crowd, this paper takes the opposite tack. It aims to show how useful it can be, in interpreting the evidence from a VAR, to have worked out theoretical models which are difficult to fit to more than stylized facts, but which can guide intuition about what to expect from the data. I take the specific example of interpreting the by now heavily worked over time series data on interest rates, money stock, output, and price level.

I have argued elsewhere [1982] that the rational expectations revolution has done for monetarism just what it has done for inflationist policy prescriptions based on the Phillips curve: it has shown that both treat an observed statistical relation as exploitable for policy purposes even though such a relation could arise in a model where it is not usable for policy. Here I present an explicit equilibrium model which verifies this assertion in detail.

The results, by showing in more detail how a purely classical equilibrium model with monetary policy irrelevant can match some time series facts, strengthen the possibility that monetary policy really is of minor importance to the business cycle. Nonetheless there are certain aspects of the actual behavior of the data which the equilibrium model misses. The gaps suggest inadequacies which, if corrected, might well reintroduce a substantial role for monetary policy and other forms of demand management.

The broader methodological implications of the exercise are that:

i) Particularly when dealing with models which mix financial and real aggregate variables, experimenting with simple behavioral models is an important safeguard against naive interpretations of VAR's or other data-based models, even when the behavioral models are too simple to fit well

ii) Simulating nonlinear behavioral models is getting easier, both because of improved techniques and because of better computational hardware. This weakens the excuse that these models are so hard to work with that papers which use them should not be expected to contain any formal statistical inference. It also weakens the excuse that they are so hard to work with that VAR modelers are justified in eschewing them in favor of intuition and common sense in interpreting their results.

iii) It is not enough that a behavioral model should match a few observed second moments in sign. By insisting on a quantitative match to the data, in as much detail as possible, we give the data a chance to be much more informative. This point is made in the context of another macromodel by Hodrick, Kocherlakota, and Lucas.

II. The RMPY VAR

The nature of the time series relations among money stock (M), interest rate (R), price level (P) and real output (Y) has been examined often, recently e.g. by Runkle and by Eichenbaum and Singleton. Monetarists, led by Milton Friedman, argued that correlations of money with income were strong and implied a role for monetary policy in generating business cycle fluctuations. Tobin showed that such a correlation could arise in a model where monetary policy did not influence the business cycle, but his example was a deterministic model. Friedman did statistical work to show that the relationship between income and money was asymmetric, with money predicting income more than vice versa, a result with no counterpart in any deterministic model. My own paper showed that this asymmetry was sharp and indeed of just the form implied by a claim that regressions of income on money recovered an exploitable structural relation. Bivariate relations between money and nominal GNP still show this pattern, as shown in the actual data panels of Tables 1 and 2.

It is interesting to note that the statistical significance of the lagged M1's in predicting YN is no stronger now than it was in my original work on this relation in 1972, despite the data accumulated since. Also, in 1972 the relation of real GNP to M1 was much weaker than that of nominal GNP to M1, according with the idea that it was hard to predict how nominal demand shocks would split up between price and real movements. But now bivariate relations between M1 and real GNP (not shown) have almost the same pattern, and slightly greater statistical strength, than the corresponding relations between M1 and nominal GNP.

It is also by now well known that nominal interest rates show substantial predictive power when introduced into an RMPY system, in the process reducing the marginal predictive value of M1 for GNP. These regularities are documented in the Actual Data panels of Table 3 and the Chart. These results make it difficult to maintain the position, once the standard monetarist position, that the money stock by itself constitutes an adequate index of monetary policy, with any attention to interest rates a possibly misleading distraction. But one can still take the position that, while both interest rates and money stock "matter", this is no weakening of the evidence that monetary policy, which affects both these variables, matters. Indeed a rise in interest rates is shown in the VAR impulse responses to be followed by a delayed, but substantial and sustained, decline in real output, much as one would expect if contractionary monetary policy produced a recession.

III. A Non-Monetarist Structural Model

We consider a purely classical, rational expectations model in which the representative agent maximizes

$$E\left[\sum_{t=1}^{\infty}\left[\frac{C_t^{\pi}(1-h_t)^{1-\pi}}{1-\tau}\right]^{1-\tau}\beta^t\right] \tag{1}$$

subject to

$$\left[C_t^3 + 2I_t^3\right]^{\frac{1}{3}} + T_t + m_t - p_t m_{t-1} + b_t - r_{t-1} p_t b_{t-1} = \frac{Y_t}{(1+\phi_t V_t)}, \tag{2}$$

$$Y_t = \theta_t K_{t-1}^{.3} h_t^{.7}, \qquad V_t = Y_t / m_t \tag{3}$$

$$I_t = K_t - .92 K_{t-1} \tag{4}$$

Here C is consumption, I is gross investment, h is hours worked, m is real balances, p is the gross rate of deflation (price at t-1 divided by price at t), b is the real value of the stock of one period bonds, r is the one-period interest rate, Y is aggregate output, V is velocity, and K is the capital stock. θ_t is a shock to productivity and ϕ_t is a stochastic process determining transactions costs.

Government chooses r, m, b, and taxes T at time t, subject to the constraint

$$T_t + m_t - p_t m_{t-1} + b_t - p_t r_{t-1} b_{t-1} = x_t, \tag{5}$$

where x is expenditures, which are taken not to enter utility or production and to be fixed exogenously.

The model has a labor-leisure choice, a variable relative price of capital and consumption goods, and transactions-based demand for money. Because the model has transactions costs absorbing real resources (the $1+\phi V$ term in the denominator of the right-hand side of (2)), monetary policy does have real effects in this model. A high average rate of inflation (low p), for example, will imply high average nominal interest rates, high velocity, high transactions costs, and lower output. However, if ϕ is small, these real effects of monetary policy will be small.

The model embodies rational expectations, but it does not produce the usual conclusion associated with classical rational expectations models -- that unanticipated monetary disturbances are the source of real effects of monetary policy. That conclusion depends on introducing into a model persistent discrepancies across agents in currently available information. Because this model has all agents alike, it is possible to verify that purely unanticipated disturbances to money supply feed directly and proportionately into the price level, with no effect on real variables. Only anticipated monetary policy disturbances, which influence expected inflation and thereby the nominal interest rate, have real effects in this model.

We postulate two equations to determine government policy, one which can be loosely thought of as a fiscal policy equation and one which can be thought of as a monetary policy equation. They are

$$T_t = .06(b_t-2)+v_t \tag{6}$$

$$\log\left(\frac{m_t}{p_t m_{t-1}}\right) = .5*\log(r(t)) + w_t \quad . \tag{7}$$

In the simulations, the exogenous processes ϕ and θ are postulated to follow mutually
independent first order markov processes, both lognormal with autoregressive parameters .8 and .9, respectively. The standard deviation of the disturbances in ϕ and θ is .01. The deterministic steady state values for ϕ and θ are set at .01 and 1.0, respectively. The x, v and w processes are also mutually

independent and independent of ϕ and θ. The standard errors of x v and w are set at .01. β was set to .98, τ to 2, and π to .7.

To solve and simulate the model, I applied the idea of backsolving, which I describe elsewhere [1984]. A quick summary of what this involves runs as follows. One finds the deterministic steady state of the model, then linearizes the Euler equations about this point. The resulting system is analyzed to find unstable roots, which are extinguished by adding equations to the system. This part of the process is equivalent to taking a linear-quadratic approximation to the original model and solving it, as did Kydland and Prescott in a seminal paper. However instead of simulating the linear-quadratic approximation, backsolving simulates the original constraints and stochastic Euler equations, obtaining a solution in which all the approximation error is concentrated in the distribution of the exogenous shock processes. That is, the resulting simulations are <u>exact</u> solutions to a model with the same objective functions and constraints as the original model, but with a slightly different specification of the exogenous shock processes. In the simulations reported here there is no indication that the exogenous shock processes have distributions very much different from those originally specified.

The simulated data panels of Tables 1 and 2 show results for a simulated run of 200 periods for this model. In this model there is little variation in output from any source except productivity shocks. In steady state transactions costs absorb about 3% of output, which is probably unrealistically high, but the 1% standard deviation shocks to this 3% form a negligible source of output variation. The one per cent standard deviation disturbances in the growth rate of money originating in w are naturally treated as policy shocks. A regression of real GNP on current and lagged values of these policy shocks in the simulated data (not reported in detail here) shows completely negligible and statistically insignificant effects of these shocks on real output.

Nonetheless it can be seen from Table 1 that the asymmetric pattern of predictive value between money and nominal income is similar in both panels. Further, the pattern of impulse responses shown in Table 2 is broadly similar. Some of the apparently greater smoothness in the response of nominal GNP to M1 shocks in the actual data may reflect the effects of time aggregation. Table 2 implies that M1 has substantially more explanatory value for nominal GNP in the simulated than in the actual data. This may reflect the unrealistic price flexibility of the model, as discussed below; but it only strengthens the point that a model with negligible monetary policy disturbances can generate strong Granger causal priority for money.

Table 3 and the Chart compare the simulated and actual data results for VAR impulse responses in a four variable system. It can be seen that the negative effect of interest rate innovations on output is reproduced in the simulated data, though the effect is immediate, instead of delayed, in the simulated data. The positive effect of money stock innovations on output also appears in the simulated data, though it is both weaker and more persistent than the effect in the actual data. On the other hand, the negative effect of interest rate innovations on nominal money balances is not reproduced in the simulations. This probably reflects the biggest defect in the simulated model -- the discrepancies in the responses of price, the third block from the top. In the simulated data, price responds sharply to every kind of innovation; in the actual data it responds much more slowly and weakly to interest rates and money, and not at all to real output.

Conclusion

The macroeconomic implications of these results are summarized in the introduction. Here we consider implications for policy and methdological issues related to agriculture. Informal interpretations of reduced form VAR impulse responses and Granger causal priority results are likely to be reliable in applications where the model contains no financial or monetary variables or where those variables are treated only as indicators of effects coming from outside the agricultural sector. If we include agricultural sector variables in a model which also includes exchange rates, money stock, and interest rates, and if we are willing to assume that effects of the agricultural sector on these variables are weak, we can reliably use responses to these variables as indicators of the effects of external forces on agriculture.

But when the issue is whether these effects originated in monetary policy decisions or in private sector disturbances to tastes and technology outside agriculture, the macroeconomic identification problems become central. Then policy conclusions become highly sensitive to identifying assumptions, and macroeconomists have not yet sorted out for themselves which of these assumptions are plausible or consistent with the data. This does not mean that sophisticated time series methods are no help in resolving these policy issues -- rather the opposite. This paper's methods, in showing that a now popular way of viewing the data (the real business cycle theory perspective) has difficulty in matching the actual data's price sluggishness, offer promise that more careful data analysis can contribute to sorting out the controversy. And when a decision has to be made, some identifying assumptions have to be made, explicitly or implictly. They ought to be made with the best possible analylsis of how well it fits the data's full range of dynamic cross-dependencies.

Table 1

Tests of Granger Causality

	Actual Data		Simulated Data	
	F statistic for hypothesis that			
	M1 causes	YN causes	M1 causes	YN causes
M1	3672 (.4X10-7)	1.097 (.36)	54.3 (.4X10-7)	.814 (.542)
YN	2.38 (.042)	4881 (.4X10-7)	7.39 (.2X10-5)	9.77 (.7X10-7)

Note: Tests based on a 5-lag VAR with constant but no trend terms. For actual data, variables were logs of nominal GNP and of nominal M1 (the latter spliced to maintain continuity across the split between M1A and M1B) over 1948:1-1988:3, quarterly data. Simulated data are from model set out in the text. Marginal significance levels are shown in parenthesis below F statistics.

TABLE 2

Bivariate Impulse Responses

	Actual Data		Simulated Data		
	Response to Shock in:				
Qtrs. Ahead	M1	YNOM	M1	YNOM	Responses of:
0	0.73	0.00	1.00	0.00	
1	1.02	-0.06	1.02	-0.09	
3	1.11	-0.06	0.94	-0.08	M1
7	1.04	-0.10	1.11	0.01	
11	1.05	-0.01	1.14	0.09	
0	0.21	1.02	1.04	1.11	
1	0.50	1.31	0.88	0.12	
3	0.83	1.66	0.90	0.24	YNOM
7	0.70	1.41	1.09	0.19	
11	0.66	1.52	1.12	0.20	

Note: See note to Table 1. All responses multiplied by 100 to give them the units of per cents. Each response column represents responses to one-standard-deviation unpredicted disturbances in the variable heading the column.

TABLE 3

IMPULSE RESPONSES

	Actual Data 1949:2-1988:3				Simulation				
	Responses to Shocks in:								
Qtrs Ahead	TBILLS	M1	PGNP	GNP82	TBILLS	M1	PGNP	GNP82	Responses of:
0	0.64	0.00	0.00	0.00	0.22	0.00	0.00	0.00	
1	0.76	0.08	0.06	0.04	0.01	-0.00	0.01	-0.04	
3	0.52	0.37	0.16	0.07	0.03	0.01	0.04	-0.05	TBILLS
7	0.26	0.06	0.24	0.03	0.01	-0.00	0.01	-0.02	
11	0.08	-0.04	0.22	0.03	0.01	-0.00	0.02	-0.01	
0	0.08	0.58	0.00	0.00	0.16	0.97	0.00	0.00	
1	-0.25	0.83	-0.02	0.03	0.16	0.97	-0.09	-0.09	
3	-0.40	0.91	-0.05	0.05	0.16	0.86	-0.23	-0.03	M1
7	-0.59	0.86	-0.11	0.09	0.20	1.07	-0.29	-0.02	
11	-0.40	0.94	-0.06	0.16	0.26	1.10	-0.24	-0.11	
0	0.02	0.09	0.48	0.00	1.21	0.82	1.14	0.00	
1	0.12	0.19	0.61	0.00	0.33	0.81	0.93	-0.41	
3	0.24	0.36	0.88	0.00	0.70	0.64	0.70	-0.62	PGNP
7	0.41	0.49	1.17	-0.04	0.64	0.85	0.37	-0.61	
11	0.41	0.50	1.29	0.00	0.56	0.94	0.24	-0.53	
0	0.15	0.18	-0.06	0.85	-0.19	0.07	-0.85	0.35	
1	0.16	0.26	0.03	1.02	-0.27	0.08	-0.74	0.36	
3	-0.23	0.40	0.13	1.14	-0.40	0.17	-0.61	0.45	GNP82
7	-0.80	-0.01	0.02	0.87	-0.33	0.16	-0.51	0.45	
11	-0.80	-0.03	0.00	0.88	-0.23	0.13	-0.38	0.33	

Notes: Actual columns are from a VAR model relating 3 month Treasury Bill Rates (TBILLS), the money stock (M1), the GNP deflator (PGNP) and GNP to 5 lags of each variable and a constant term, quarterly data. All variables but TBILLS were in natural logs, and the corresponding responses have been multiplied by 100 to give them the units of percents. Responses are all to one-standard-error increases in the innovation in the variable heading the column. Simulation columns are from a VAR estimated from 200 periods of data for r, m, p and Y from the theoretical model laid out in the text.

REFERENCES

Bernanke, Ben [1986], "Alternative Explorations of the Money-Income Correlation," in Carnegie-Rochester Conference Series on Public Policy (Amsterdam: North Holland)

Blanchard, Olivier and Mark Watson [1986], "Are All Business Cycles Alike?" in The American Business Cycle, R.J. Gordon, ed.(Chicago: U. of Chicago Press).

Eichenbaum, M. and K. Singleton [1986], "Do Equilibrium Real Business Cycle Theories Explain Postwar U.S. Business Cycles?" in NBER Macroeconomics Annual 1986, S. Fischer, ed.

Hansen, Gary D. [1985], "Indivisible Labor and the Business Cycle," Journal of Monetary Economics v.16, November.

Hodrick, R.J., N. Kocherlakota and D. Lucas [1988], "The Variability of Velocity in Cash-in-Advance Models," Northwestern University discussion paper.

Kydland and Prescott [1982], "Time to Build and Aggregate Fluctuations," Econometrica, November.

Runkle, David [1987], "Vector Autoregressions and Reality," Journal of Business and Economic Statistics October.

Sims, C.A.[1986], "Are Forecasting Models Usable for Policy Analysis?" Quarterly Review of the Federal Reserve Bank of Minneapolis, Winter.

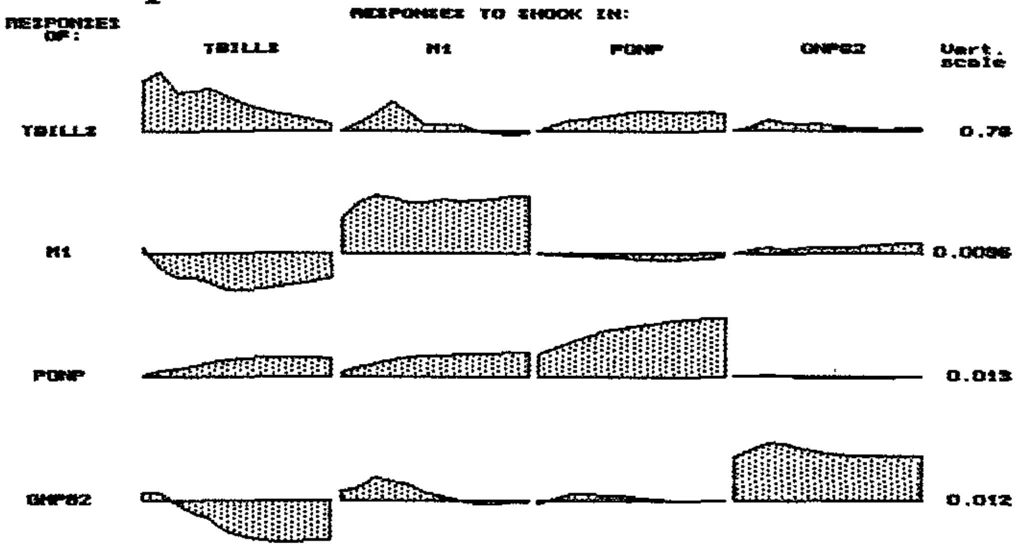
Sims, C.A. [1982], "Policy Analysis with Econometric Models," Brookings Papers on Economic Activity.

Sims, C.A. [1972], "Money, Income and Causality," American Economic Review 1972.

Sims, C.A. [1985], "Solving Nonlinear Stochastic Equilibrium Models 'Backwards'", University of Minnesota Center for Economic Research Discussion paper no. 206.

Tobin, James [1970], "Money and Income: Post Hoc Ergo Propter Hoc?" Quarterly Journal of Economics May.

Responses to Shocks, Actual Data



Responses to Shocks, Simulated Data