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Abstract

This paper puts forward a method of policy simulation with an existing macroeconometric model under the maintained assumption that individuals form their expectations rationally. This new simulation technique grows out of Lucas' criticism that standard econometric policy evaluation permits policy rules to change but doesn't allow expectations mechanisms to respond as economic theory predicts they will. The technique is applied to versions of the St. Louis Federal Reserve model and the Federal Reserve-MIT-Penn (FMP) model to simulate the effects of different constant money growth policies. The results of these simulations indicate that the problem identified by Lucas may be of great quantitative importance in the econometric analysis of policy alternatives.

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This paper presents simulation results from two econometric models which are manipulated as if the rational expectations hypothesis holds. Unlike standard simulation techniques which impose different government policy rules without allowing agents' methods of forming expectations to change in response, the simulation method used here allows individual expectations to change in harmony with the simulated policy change. The hybrid system produced by using this procedure is less satisfactory than a model which includes rational expectations among its maintained behavioral hypotheses during estimation. Nevertheless, rational expectations simulations of existing "nonrational" models can provide insights into the structure of those models and may give some indication of the quantitative importance of the rational expectations critique of standard econometric policy evaluation.

Background

The inability of large-scale macroeconometric models to predict the quantitative effects of alternative policy rules has been explained in a new way by Lucas [1976]. He argues that the problem stems from the static expectations mechanisms embedded in most structural models. Theory implies that when a change in policy is undertaken, agents in the economy will revise the expectations rules which guide many of their current decisions. However, as Lucas points out, standard models are simulated under the assumption that producers and households will continue to act on the basis of forecasts generated by the outmoded rules which were considered optimal under the previous regime.

Whether these hypothesized changes in forecasting rules are important enough to invalidate current simulation methodology is an empirical question which should be of great concern to model builders and users. Empirical investigation of this point involves some rather difficult inference problems. However, it seems reasonable to maintain that macroeconometric models in which forecasting rules adjust to policy changes have the potential to represent the responses of the real economy more accurately than the static expectations models now employed.

A simple way to model adjusting forecast rules is to incorporate the rational expectations hypothesis, initially framed by Muth [1961] and applied in the empirical work of Shiller [1972] and Sargent [1973a], among others. Basically, the hypothesis is that individuals act as if responding to the true distributions of economic random variables conditional on the information available to them. Careful empirical testing of the rational expectations hypothesis and the closely allied natural rate hypothesis has not called for outright rejection, though much testing remains to be done. (See Sargent [1976] for an excellent survey.)

If the rational expectations hypothesis stands up to further empirical testing, it should be included in the behavioral specifications of models. The estimation of a large, rational expectations macroeconometric model is a costly, time-consuming project. While research on the rational expectations hypothesis continues, it seems useful to develop a method for simulating existing models under the added assumption that expectations adjust in an optimal manner.

This paper presents one possible simulation method which incorporates a rationality postulate. The method can be used in any existing macroeconometric model. Policy simulations using this method may provide better forecasts than standard simulations. At the very least, comparisons of the two types of simulations will provide some indication of the extent to which the policy responses implied by the standard simulations depend on the "slow learning" of economic agents.

This paper includes illustrative simulations using versions of the St. Louis Federal Reserve model and the FRB-MIT-Penn (FMP) model. These policy simulations indicate that the real effects of monetary expansion in standard simulations with these models derive almost solely from the slowness of agents to perceive policy changes.

Rational Simulations from Nonrational Models

Rational expectations simulations may be produced by manipulating an existing econometric model under the maintained assumption that the forecasts implicit in the behavioral relations adjust by precisely the amount that the entire model predicts actual outcomes will change as a result of a given policy change. This process can be explained most easily by using an example. We shall consider a simplified linear macroeconometric model of the form

$$p_t = az_t + v_t \quad (1)$$

$$y_t = bz_t + cp_t^e + u_t \quad (2)$$

$$p_t^e = \sum_{s=1}^{n} d_s p_{t-s} \quad (3)$$

where p_t and y_t are endogenous variables for price and production, respectively, z_t is a vector of exogenous and predetermined variables, p_t^e is an explicit forecast of price[1/] in period t based on information available at the beginning of period t, c and the d's are scalar coefficients, a and b are coefficient vectors, and u_t and v_t are white-noise error terms. Equation (1) is the reduced-form equation for price; equation (2) is an example of a behavioral relation, perhaps a supply decision; and equation (3) is an assumed price expectations rule.

In existing econometric models, equations (2) and (3) are combined and estimated in the form[2/]

$$y_t = bz_t + c \sum_{s=1}^{n} d_s p_{t-s} + u_t. \tag{4}$$

Forecasts for p_t and y_t are generated from equations (1) and (4) by setting the disturbances u_t and v_t equal to their means (zero) to yield

$$F(p_t) = az_t \tag{5}$$

and

$$F(y_t) = bz_t + c \sum_{s=1}^{n} d_s p_{t-s} \tag{6}$$

where $F(x_t)$ is defined as the model forecast of x_t. Equations (5) and (6) are usually used for forecasting. Alternative policies are simulated by assuming different settings of some of the z's and calculating the expected outcomes using (5) and (6).

While equations (5) and (6) may produce accurate forecasts over a period of rather stable policy, they may be quite unsatisfactory for the analysis of the effects of alternative settings of the policy variables included in z_t. Simulations using equation (6) implicitly assume that the agents whose behavior is represented by ($\overset{4}{\cancel{6}}$) continue to form price expectations using equation (3). Even if the parameters of equation (3) were chosen to mimic the price process quite closely over the sample period, it would not be optimal for those agents to persist in using equation (3) in the face of a policy change which is known to alter the price process significantly.

In order to produce a rational expectations forecast, we reformulate the basic model and replace the original expectations assumption (3) with the alternative hypothesis that expectations are equal to the model's own forecast, i.e.,

$$p_t^e = F(p_t) = az_t. \tag{7}$$

Substitution of (7) into equation (2) yields

$$y_t = bz_t + caz_t + u_t = (b+ca)z_t + u_t. \tag{8}$$

The forecasts from this new structure are derived from equation (5) and the new equation

$$F(y_t) = (b+ca)z_t \tag{9}$$

using the estimates of a, b, and c from the original system. Comparison of equations (6) and (9) will show that equation (9) predicts a different effect on y_t of a change in z_t. If agents actually anticipate the impact of a change in z_t on p_t, equation (9) may yield a more accurate prediction of their response to that policy change.

This example implies that the price forecasts of the model will not be affected by the rational expectations modification. That would be true only if the model were recursive with p_t being determined prior to y_t. If p_t and y_t are determined simultaneously, the coefficients of the reduced-form equation for p_t (vector a) will depend on the coefficients of equation (4). Replacing (4) by (8) will, in general, alter the coefficients of equation (1).

The changes made to the computer coding to simulate rational expectations are valid even in the general simultaneous case. The distributed lag term in equation (4) is replaced by the term for p_t in the simulation program. Simultaneous solution of the new system of equations will preserve equation (7), and, in general, both the price and output forecasts will differ from those of the original model.

This procedure is, however, far from mechanical. In working with equations of the form of (4), one must first be sure that the distributed lag expression which one is replacing corresponds solely to an agent's expectations and doesn't involve, for example, some technological aspects as well. Second, as equation (4) is usually estimated by time series methods, the coefficient c is not identified econometrically. Often the ad hoc identifying restriction

$$\sum d_s = 1$$

has been maintained. For many economic variables, the optimal predictor would not obey that restriction (or the smoothness restrictions often added to it). A suitable identifying restriction may sometimes be derived from economic theory, e.g., invoking the efficient markets hypothesis in portfolio demand. Without strong cues from the underlying microeconomics or independent empirical evidence, one's judgment must come into play. Several methods, each of which would be appropriate for some class of models, can be suggested.

The mathematical and computational problems both become more difficult if the expectations involved in equation (2) are forecasts of economic variables for several periods into the future rather than a single period. Many properly posed multiperiod stochastic decision problems yield a solution in terms of forecasts which reach infinitely far into the future. Truncation of this infinite forward distributed lag is a defensible approximation, but if even a single future term remains in a decision rule, simulation becomes quite complicated. The time path of the model can no longer be solved simply period by period, since the forecast of the model for time t+k depends on the forecast of some variables for dates t+k+1 and later. This is an inconvenient consequence of using the model's own forecasts as proxies for expectations.

One possible method of simulation in such a situation is to run a sequence of multiperiod predictions using the forecasts from one entire simulation as the expectations for the next simulation. If such a sequence converges, the result will be an internally consistent solution where agents' expectations for future periods are the same as the model's predictions. This has not been implemented to our knowledge.[3] This method would require some terminal assumption about certain variables, e.g. inflation, many periods in the future. It would be necessary to posit some "reasonable" number as the expected value of the inflation rate for a period twenty or thirty quarters in the future. In such a system, one would at least be able to determine exactly what effect alternative terminal assumptions would have on the experiments performed.

In the next section we present the results of simulating the effects of certain policy rules in two existing econometric models, first in the standard manner and then by transforming expectations in accordance with the rational expectations hypothesis.

Experiments With Two Macroeconometric Models

We report the results of simulations of constant money growth rates using two econometric models, the St. Louis Federal Reserve model and a version of the FRB-MIT-Penn (FMP) model.[4] For each model, three ex post simulations were run using the unaltered model structure to represent the effects of increasing the money supply (M1) at four, six, and eight percent per year. After the structure was transformed as described above, the three simulations were repeated with all of the exogenous variables and all of the coefficients (except those connected with expectations) at the same settings used for the first set of simulations.

Since our purpose is illustrative, many aspects of these tests which might be treated in a detailed systematic evaluation were not considered. The simulations are deterministic rather than stochastic. The exogenous variables are set at actual levels rather than forecast by the generating mechanism actually used for projecting future values. In the FMP model, no intercept adjustments were used. The simulation periods differ. With one exception, mentioned below, we know of no reason why the choices we have made are likely to make the results reported here unrepresentative of the two models. The simulation results are presented in the next two subsections. The final subsection deals with another type of possible policy experiment.

A. The St. Louis Model

These simulation experiments were carried out using the version of the model described in the original paper by Anderson and Carlson [1970]. However, for illustration, we will consider the following simplified version which contains five endogenous variables, three exogenous variables, and three random disturbances.

$$\Delta p_t^e = A(L) \frac{p_{t-1}}{u_{t-1}} \qquad (10)$$

$$\Delta y_t = B(L)m_t + C(L)g_t + v_{1t} \tag{11}$$

$$\Delta p_t = D(L)(\Delta y_t - xf_t + x_{t-1}) + .86\Delta p_t^e + v_{2t} \tag{12}$$

$$x_t = y_t/p_t \tag{13}$$

$$u_t = G(L)\left(\frac{xf_t - x_t}{xf_t}\right) + v_{3t} \tag{14}$$

where A(L),B(L) . . . are one-sided polynomials in the lag operator L. The five endogenous variables are nominal GNP(y), constant dollar GNP(x), the implicit GNP deflator (p), the unemployment rate (u), and the expected change in the price level (Δp^e). The three exogenous variables are the money supply (m), government expenditures (g), and full-employment output (xf). The v_i's are the random disturbances.

Equation (10) is an expectations equation where expected inflation is a weighted sum of past inflation rates. The weights, however, are variable and vary inversely with the unemployment rates in the last periods. The authors call equation (11) the total spending equation and equation (12) the price equation. Equation (13) is the identity for real output, nominal output, and the price level. Equation (14) relates the unemployment rate to capacity utilization, a rough empirical approximation sometimes called "Okun's Law." Equations (10) and (12) correspond to equations (3) and (2) in the preceding section.

In order to simulate this model under the assumption of rational expectations, we simply drop equation (10) from the model and replace Δp_t^e in equation (12) by the expression Δp_t to yield:

$$\Delta p_t = C(L)(\Delta y_t - xf_t + x_{t-1}) + .86\Delta p_t$$

or, more compactly

$$\Delta p_t = \frac{1}{1-.86} C(L)(\Delta y_t - xf_t + x_{t-1}).$$

The effects of 4, 6, and 8 percent constant money growth rates in the original and RE versions of the St. Louis model were simulated from the initial conditions of 1960I by solving dynamically through 1965IV. Both sets of simulations used actual values of the exogenous variables (excluding m, of course). All of the coefficients were the same for both models. Tables 1 and 2 contain the inflation and unemployment rate paths from those simulations. The quarterly inflation rates have been converted to annual rates.

The simulations using the original St. Louis model demonstrate an exploitable trade-off between inflation and unemployment. Higher money growth rates not only increase the rate of inflation but also decrease the unemployment rate substantially. However, when the rational expectations adjustment is made to the structure of the St. Louis model, that trade-off virtually disappears.

There is almost no change in the unemployment rate path when the money supply growth rate is increased from 4 percent to 8 percent. The unemployment rates for the 4 and 8 percent rational simulations never differ by more than six-tenths of 1 percent and the mean difference is only three-tenths. In contrast, the 4 and 8 percent simulation unemployment rates from the original model differ, at times, by over 3 percent and the mean difference is 1.2 percent, four times larger than that for the rational expectations simulations.

The large short-term decreases in the unemployment rate produced by increasing the money growth rate in the original model result from

Table 1

Simulation Results From Original Version of St. Louis Model

	Inflation Rate*			Unemployment Rate		
M1 Growth Rate	4%	6%	8%	4%	6%	8%
Date						
1960 I				5.8	5.8	5.8
II	1.9	2.0	2.0	5.9	5.8	5.8
III	1.7	1.9	2.1	5.9	5.7	5.5
IV	1.7	2.0	2.3	5.6	5.3	4.9
1961 I	1.7	2.2	2.7	5.3	4.7	4.1
II	1.8	2.5	3.2	5.0	4.2	3.5
III	2.0	2.9	3.7	4.7	3.8	2.9
IV	2.2	3.2	4.2	4.5	3.5	2.4
1962 I	2.3	3.6	4.8	4.4	3.2	2.0
II	2.5	3.9	5.4	4.2	2.9	1.5
III	2.7	4.3	6.1	4.0	2.6	1.2
IV	2.8	4.7	6.9	4.0	2.5	1.0
1963 I	3.0	5.0	7.9	4.0	2.4	0.9
II	3.0	5.3	9.2	4.0	2.4	1.0
III	3.1	5.7	10.8	4.1	2.5	1.2
IV	3.2	6.1	12.0	4.1	2.5	1.4
1964 I	3.3	6.5	13.8	4.1	2.6	1.8
II	3.4	7.0	15.3	4.0	2.6	2.3
III	3.5	7.3	16.7	3.9	2.6	2.9
IV	3.6	7.7	17.8	4.0	2.9	3.7
1965 I	3.6	8.1	18.8	4.2	3.2	4.6
II	3.7	8.4	19.4	4.3	3.5	5.6
III	3.8	8.6	19.6	4.3	3.7	6.4
IV	4.0	8.8	19.5	4.1	3.8	7.2

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*Annual percentage rate

Table 2

Simulation Results From Rational Expectations Version of St. Louis Model

	Inflation Rate*			Unemployment Rate		
M1 Growth Rate	4%	6%	8%	4%	6%	8%
Date						
1960 I				5.8	5.8	5.8
II	1.0	1.5	2.0	5.8	5.8	5.7
III	1.3	2.6	3.8	5.7	5.6	5.4
IV	2.5	4.5	6.5	5.5	5.2	5.0
1961 I	4.1	6.7	9.4	5.2	4.9	4.6
II	5.4	8.5	11.6	5.1	4.8	4.5
III	6.2	9.5	12.7	5.1	4.9	4.6
IV	6.2	9.5	12.7	5.3	5.0	4.8
1962 I	5.8	8.8	11.8	5.4	5.2	5.0
II	5.2	8.0	10.8	5.5	5.4	5.2
III	4.4	7.0	9.5	5.5	5.4	5.2
IV	3.5	5.9	8.3	5.6	5.5	5.3
1963 I	2.7	5.0	7.3	5.6	5.5	5.4
II	2.0	4.4	6.7	5.6	5.5	5.3
III	1.7	4.1	6.4	5.6	5.5	5.3
IV	1.8	4.2	6.4	5.5	5.4	5.2
1964 I	2.3	4.5	6.9	5.4	5.3	5.1
II	3.1	5.3	7.4	5.3	5.1	4.9
III	3.5	5.6	7.6	5.2	5.0	5.0
IV	3.4	5.6	7.6	5.3	5.1	5.0
1965 I	3.1	5.3	7.3	5.4	5.2	5.0
II	2.9	5.1	7.2	5.4	5.3	5.1
III	3.1	5.3	7.4	5.4	5.2	5.0
IV	3.6	5.6	7.6	5.2	5.1	4.9

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*Annual percentage rate

systematically mistaken expectations of the inflation rate. This can be seen by examining the difference in the rate of inflation and the expected rate of inflation implicit in different model simulations. Table 3 includes the values of the "expected forecast error" calculated as

$$FE = \left(\frac{\Delta p_t^e}{p_{t-1}}\right) - \left(\frac{\Delta p_t}{p_{t-1}}\right).$$

where Δp_t^e, Δp_t, and p_{t-1} are values from the 2 and 8 percent money growth simulations of the original model. The 2 percent growth rate was chosen for this illustration because 2 percent was approximately the average rate of money supply growth over the sample period.

The larger absolute size of the expectation errors in the 8 percent simulation is to be expected since an exogenous variable takes on a pattern of values outside the range of experience; but, the serial pattern of the errors is quite revealing. The agents in this model are expected to underestimate the inflation rate by more than 3 percent for six consecutive quarters and by more than 2 percent for ten consecutive quarters. The slowness with which expectations "catch up" to actual inflation will seem "unrealistic" to many readers. But the belief, based on a simulation of this model, that a sustained high rate of money growth will lower the unemployment rate is predicated on just such a pattern of forecast errors.

B. The FMP Model

The changes made to the FMP model to impose rational expectations were much more extensive than those made to the St. Louis model. Expectational distributed lags were replaced in several equations. The most

Table 3

Errors in Forecasts of Inflation Implicit in Simulation of Original St. Louis Model

	2% Money Growth	8% Money Growth
	Forecast errors* in percent at annual rates	
1960I	0.25%	0.20%
	0.34	0.10
	0.39	-0.16
	0.39	-0.62
1961I	0.31	-1.18
	0.22	-1.76
	0.14	-2.31
	0.07	-2.78
1962I	0.00	-3.16
	-0.08	-3.47
	-0.12	-3.65
	-0.11	-3.69
1963I	-0.07	-3.59
	0.00	-3.33
	0.07	-2.94
	0.13	-2.42
1964I	0.13	-1.82
	0.09	-1.15
	0.07	0.46
	0.10	0.46
1965I	0.14	1.31
	0.16	2.11
	0.10	2.82
	-0.01	3.46

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*Negative value indicates inflation will be underestimated by agents.

important of these were the Phillips curve, the demand curve for consumer durables, the cost-of-capital identity, and the interest rate term-structure equation.

The coefficients of the expectations terms were chosen to be consistent with the natural rate and efficient market hypotheses. (In the Phillips curve, for example, the coefficient of expected inflation was chosen to be exactly one.) These choices probably maximized the impact of this rational expectations alteration to the model's structure.

The results of two sets of constant money growth simulations are reported in Tables 4 and 5. As in the St. Louis model experiments, the imposition of rational expectations greatly reduces the real impact of sustained monetary expansion. However, unlike the St. Louis model, this version of the FMP demonstrates very small price effects from increased money supply growth. This probably results from using a simulation period in which the untended model generates high rates of unemployment. In the FMP model, monetary expansion has little effect on prices at such high unemployment levels. Simulation over a different sample period which produced substantially lower unemployment rates would probably demonstrate larger price effects.

C. Further Considerations

In the examples presented here, models are altered to impose the condition that expectations of the current period's (as yet unobservable) prices be consistent with the model's own forecasts. Rationality in the forecasting of other important variables can be handled in the same way.

Table 4

Simulation Results From Original Version of FMP Model

	Inflation Rate*			Unemployment Rate		
M1 Growth Rate	4%	6%	8%	4%	6%	8%
Date						
1971 I				7.6	7.6	7.6
II	3.4	3.4	3.4	7.6	7.6	7.6
III	1.7	1.7	1.7	7.0	6.9	6.8
IV	1.4	1.4	1.4	6.9	6.8	6.7
1972 I	5.7	5.7	5.7	7.7	7.5	7.3
II	0.8	0.8	1.4	7.8	7.4	7.1
III	2.5	2.8	2.8	7.4	6.9	6.4
IV	3.6	3.9	3.9	8.0	7.2	6.6
1973 I	4.7	4.7	4.9	8.3	7.3	6.5
II	5.1	5.4	5.7	8.4	7.0	5.9
III	4.8	4.8	5.3	8.6	6.7	5.1
IV	4.0	4.7	5.5	8.5	6.1	4.0
1974 I	6.0	6.8	9.1	8.3	5.5	2.9
II	5.9	0.5	4.1	8.6	5.4	2.3
III	3.1	4.4	9.5	8.6	5.0	1.6

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*Annual percentage rate

Table 5

Simulation Results From Rational Expectations Version of FMP Model

	Inflation Rate*			Unemployment Rate		
M1 Growth Rate	4%	6%	8%	4%	6%	8%
Date						
1971 I	4.6	4.6	4.6	7.7	7.7	7.7
II	4.6	4.6	4.6	8.0	8.0	8.0
III	3.1	3.1	3.2	7.9	7.8	7.8
IV	1.1	1.1	1.2	8.4	8.3	8.3
1972 I	6.2	6.1	6.2	9.6	9.6	9.5
II	1.1	1.2	1.6	10.0	10.0	9.9
III	3.0	3.0	3.0	9.8	9.7	9.6
IV	3.6	3.6	3.7	10.3	10.2	10.1
1973 I	4.3	4.4	4.4	10.2	10.0	9.9
II	4.6	4.8	4.9	9.4	9.2	9.0
III	2.7	3.0	3.3	8.3	8.1	7.8
IV	2.4	2.9	3.6	6.6	6.3	5.9
1974 I	5.2	5.9	7.5	4.4	4.0	3.6
II	-0.3	2.1	6.7	2.4	2.0	1.4

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*Annual percentage rate

In particular, a consumption function derived from the life-cycle hypothesis relates current consumption to current and (expected) future incomes. If the coefficients of those forecast terms can be identified econometrically, the multiperiod simulation technique proposed above could be used to implement rational expectations of future income.

In particular, simulation of the effects of different tax policies in a model which maintained efficient forecasts of future incomes might provide an interesting comparison with the recent results of Modigliani and Steindel [1977]. They find that simulations of the MPS and DRI models seem to imply that a temporary tax rebate provides more short-term stimulus to the economy than a permanent tax cut of equal dollar value in the first year of the policy. It is possible that the one-time rebate would not cause agents to revise their expectations of future incomes upward, while the permanent tax cut might engender such optimism. (In fact, in the case of the rebate, recognition of the created tax liability might suggest a downward adjustment.) However, the distributed lags of those two models cannot distinguish between these two cases. The large income increment in the quarter the rebate is disbursed will unavoidably cause the "agents" of those models to project higher incomes. In a model which treated expectations explicitly, the results of the Modigliani-Steindel experiment might be quite different.

Conclusion

Lucas' theoretical objections to current econometric policy evaluation and the failure of empirical tests to reject the natural rate-rational expectations hypothesis cast doubt on the ability of standard policy simulations to represent the effects of different policies. This paper provides a method for simulating standard models under the assumption of rational expectations when reestimation under that assumption is considered too costly. The results of the rational expectations simulations presented here indicate that the point raised by Lucas is of potentially great quantitative importance for econometric policy evaluation.

Footnotes

[1] Price is used only as an example of a variable whose future values may be anticipated. This method could be applied wherever expectations are explicitly modeled.

[2] Examples of such equations may be found in the equation listing of almost any large model.

[3] Building on an earlier version of this paper, Fair [1977] recently performed dynamic simulations which utilize rational expectations in the bond and stock markets. In his experiments, the real effects of monetary expansion are approximately halved.

[4] The references for these models are well-known. The St. Louis Federal Reserve model was first described in Anderson and Carlson [1970]. An early version of FMP is described by deLeeuw and Gramlich [1968]. The version of the FMP we actually use is that existing at the Federal Reserve just prior to the major GNP accounts version. A newer version has been specified and estimated using revised data.

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