JAMES BARTH
George Washington University and National Science Foundation

ROBIN SICKLES
University of Pennsylvania

PHILIP WIEST
George Mason University

Assessing the Impact of Varying Economic Conditions on Federal Reserve Behavior*

The purpose of this paper is to examine the nature of the response by the Federal Reserve to changes in economic conditions. Unlike previous studies, however, the specification of the reaction function for the Federal Reserve employed here will take account of the fact that the marginal response may vary with the severity of economic conditions. Whether or not this is the case is determined by developing a generalized spline estimator. It is found that the Federal Reserve's reaction to economic conditions does indeed vary with the severity of these conditions. The implications of this finding are discussed.

1. Introduction

The response of the Federal Reserve to changes in its primary policy objective variables, unemployment and inflation, has received considerable attention in recent years. This is understandable since knowledge about the Federal Reserve's behavior is necessary to assess its performance in dealing with these two economic problems as well as to determine whether it behaves in a way that is compatible with the stated policies of the Administration. Knowledge about Federal Reserve behavior is also important because anticipated systematic policy actions may influence the expectations and thus behavior of the public, which in turn will influence the impact of these policy actions on economic activity.[1] In addition, regardless of expectations, if the Federal Reserve responds systematically to changes in its objective variables, macroeconomic models

*The authors acknowledge helpful comments provided by Lawrence Davidson, Richard Froyen, David Guilkey, William Kelly and Peter Schmidt.

[1]For a discussion of the role of expectations in macroeconomic models, see Swamy, Barth and Tinsley (1980).

Journal of Macroeconomics, Winter 1982, Vol. 4, No. 1, pp. 47–70

will provide biased estimates of the impact of current period policy actions on these objective variables. This bias results from the presence of feedback in the relationship.[2]

The purpose of this paper is to examine the nature of the response by the Federal Reserve to changes in its objective variables. Unlike previous studies, however, this specification of a reaction function for the Federal Reserve takes into account the likelihood that the marginal response of the Federal Reserve to changes in inflation and unemployment varies with the levels of these variables. That is, the marginal response will be permitted to vary over time depending on the severity of inflation and unemployment. Whether or not this is the way the Federal Reserve behaves will be determined by developing a generalized spline estimator. The advantage of this estimator is that it permits an independent variable in a regression equation to take on different functional relationships with respect to the dependent variable in the various subintervals of the domain of the independent variable. If the Federal Reserve does indeed respond differently depending upon the severity of inflation and unemployment, spline functions will capture this type of behavior.

Previous studies of Federal Reserve reaction functions exhibit substantial variation with respect to both the specification of the regression equation and the time period examined. These studies have reached no consensus regarding the degree of importance to be attached to alternative objectives or to the stability of the Federal Reserve's reactions. More specifically, the results of several of these studies suggest that the behavior of the Federal Reserve has shifted over time. Two recent studies, for instance, report that the Federal Reserve's reactions to changes in the values of ultimate objective variables have changed since 1970, when the Federal Reserve began to express more concern over monetary aggregates in its directive to the manager of the open market account.[3] Two other studies have suggested that the response of the Federal Reserve to economic conditions has systematically shifted with Presidential Administrations.[4] Although both of these studies conclude

[2]See Goldfeld and Blinder (1972) for an excellent discussion of these feedback effects.

[3]DeRosa and Stern (1977) and Chase Econometrics (1978) both suggest that the Federal Reserve's operating behavior has changed since 1970, being more concerned with controlling the money supply as one of its objectives since that year.

[4]See Froyen (1974) and Potts and Luckett (1978). Both studies estimate reaction

that the unemployment rate appears to induce more of a response than other explanatory variables, it is concluded that the ordering of responses to the objective variables ". . . does appear to be influenced by the political temper of the times."[5]

But the possibility that the marginal response of the Federal Reserve to changes in its objective variables may vary depending on the current level of these variables, or on the severity of economic conditions, has not been fully appreciated in previous studies. The Federal Reserve's response, for instance, to a one-half percentage point increase in the unemployment rate may be quite different when the unemployment rate is 3.5 percent than when it is 7.0 percent, assuming that the divergence from the perceived natural rate is different in the two periods. The same may be true of other important objective variables, such as the inflation rate.

If this is the case, previous studies examining the behavior of the Federal Reserve have incorrectly specified the reaction function by employing a restrictive and more traditional linear reaction function. Studies which ignore the possibility of the sort of structural change in the reaction function indicated here may have attributed the structural instability of the parameters over time to incorrect or only partial causes, such as changes in Presidential Administrations. It is therefore important to estimate a less restrictive functional form in which the marginal response is permitted to vary with economic conditions so that one may obtain a better understanding of actual Federal Reserve behavior. This can be done by employing a spline function to estimate the reaction function.

Briefly, spline functions are defined as piecewise polynomials of a predetermined degree, r, which are specified by dividing the range of an independent variable into several subintervals separated by a set of points called knots. The polynomial functions are then smoothly joined together at the knots so that there are r-1 continuous derivatives at each knot. Spline functions represent an alternative estimation technique to that of a single polynomial function over the entire range of the values of the independent variable since they do not restrict the relationship to a specific functional form over the entire range. Instead, they allow the functional form

functions over subintervals corresponding to the Eisenhower, Kennedy-Johnson, and Nixon (or Nixon-Ford) administrations to evaluate the impact of different administrations on policy-making.

[5]Potts and Luckett (1978), p. 532.

and thus the estimate of the response of the dependent variable to independent variables to vary over different ranges. This generally allows for a better fit of the relationship. Spline functions also represent a more general form than a piecewise linear function in that they do not restrict the relationship to a series of linear segments. Additionally, the restriction that there be r-1 continuous derivatives at the knots, or the end-points of the intervals, ensures the smoothing of the function at these points. This means that the function is continuous and differentiable over its entire range and that estimates of the coefficients vary gradually across intervals. Without these restrictions, abrupt shifts in policy would be artifically introduced as is the case when employing a piecewise linear function. A gradual change in policy is more reasonable to expect, a priori, than abrupt and discontinuous changes. More importantly, this smoothing allows the parameter estimates and the goodness of fit to be less sensitive to the choice of knot values and to the number of intervals than those of a traditional piecewise function.

As has been recently shown by Buse and Lim (1977), and noted by Suits, Mason, and Chan (1978), the spline estimator is a special case of restricted least squares. One may therefore correct for the presence of any correlation in the residuals of the reaction function by using a generalized restricted least-squares algorithm.[6] Furthermore, as was mentioned by Suits, Mason and Chan (1978), no studies have thus far employed a spline function in the direct estimation of the coefficients of an equation with more than a single independent variable. Most studies require several explanatory variables and most time-series studies encounter disturbance terms which exhibit autocorrelation and hence require generalized least-squares estimation. The estimator employed in this study builds on those used by Poirier (1973); Barth, Kraft and Kraft (1976); Buse and Lim (1972); and Suits, Mason and Chan (1978) by satisfying these modelling requirements jointly, using generalized least squares under linear constraints [(Theil (1971)].

2. Specification of the Reaction Function

The general form of the Federal Reserve reaction function to be estimated is the following:

[6]See Theil (1971).

$$I = f(P, U, \Delta r, TS, FES). \quad (1)$$

This equation states that the Federal Reserve adjusts its policy instrument (I) in response to two ultimate policy objective variables, the inflation rate (P) and the unemployment rate (U). The policy instrument is also assumed to be used to maintain stability in financial markets by responding to changes in the rate of interest (Δr) and to accommodate the needs of trade by responding to the level of total sales (TS). Finally, the Federal Reserve is hypothesized to vary the instrument to reinforce fiscal policy actions by responding to the size of the full employment budget surplus (FES) of the federal government. Of course, the values of the estimated coefficients of equation (1) do not provide direct information on the priorities of the Federal Reserve. The reaction function is derived by optimizing a utility or preference function of the Federal Reserve subject to a constraint consisting of a macroeconomic model of the economy. The reaction function coefficients therefore embody both Federal Reserve preferences and the expected impact of its actions.[7] These coefficients thus enable one to determine how, if not why, the authorities have responded to varying economic conditions.

The anticipated signs of the coefficients on each of these explanatory variables depend, of course, on the particular instrument being used. For the purpose of this study, the monetary base is chosen as the monetary policy instrument.[8] The Federal Reserve exercises considerable control over this variable, either directly through its own actions or indirectly through inaction. In the former case, the Federal Reserve can engage in open market actions designed to change the monetary base, while in the latter case the Federal Reserve may take no action to offset changes in the base brought about by movements in "non-controllable" sources of the base. The choice of a monetary aggregate as the instrument variable is consistent with many other studies of Federal Reserve re-

[7]See, for example, Wood (1967).

[8]One might argue that a more appropriate variable would be the sum of unborrowed reserves plus currency held by the public (an adjusted monetary base). However, in an earlier study, Froyen (1974) employed both the monetary base and this alternative measure in his study of the Federal Reserve reaction function. Since the results for the two measures were virtually identical (in terms of signs and significance of estimated coefficients) in that study, it was decided not to employ both variables here.

action functions.[9] This means that the estimates of this study can be directly compared to the results of these other studies. Furthermore, data on the monetary base are available over the entire time period of our analysis (1953–1978). For all of these reasons, the monetary base will be used as the policy instrument in this study.

An important requirement in specifying a reaction function is to allow for a gradual adjustment to changes in explanatory variables. When the Federal Reserve responds to its ultimate policy objective variables, inflation and unemployment, it is likely to be responding to the values of each of these variables over several time periods, not just to those for the most recent period. Although the most recent value may be important for the monetary authorities to consider, a large, single-period change in the value of a variable may be a temporary and reversible aberration caused by dislocations in one sector of the economy. Such movements may not be indicative of a lasting change in economic conditions. This is particularly true when the time period over which the variable is measured is as short as a month.

A four-month moving average of past values, from $t - 1$ to $t - 4$, of the explanatory variables is employed to capture this effect. Preliminary results obtained by treating these variables as expected levels and by generating their predicted contemporaneous values from an estimated reduced form [see, for example, Abrams, Froyen and Waud (1980)] proved less satisfactory. Several other studies have attempted to account for the gradual response of the Federal Reserve by employing a lag function.[10] However, for the purposes of this study the use of a distributed-lag function is both impractical and quite cumbersome. The reason is partly a shortcoming of the general functional form of the spline function, which requires both a substantial number of parameters to be estimated and a number of restrictions to be imposed. Imposing a distributed-lag procedure would multiply the number of parameters by the number of periods of the lag length. Apart from the large number of parameters which would have to be estimated, it is not at all clear how one would interpret the estimates of the parameters of

[9]See, for example, Froyen (1975) and Wood (1967). Wood used U.S. Government Security holdings by the Federal Reserve rather than the monetary base as the policy instrument variable.

[10]See, for example, Froyen (1974), who used a polynomial distributed lag function, and DeRosa and Stern (1977), who used an unrestricted lag structure.

such a function since allowance is being made for the lag distribution to warp depending on its level. Since this study is mainly interested in the extent to which the Federal Reserve's response to changes in the inflation and unemployment rates depends on the level, or severity, of these variables, sacrificing some of the detailed information on timing yielded by the use of a distributed-lag structure was necessary to examine this effect.

A cubic spline (i.e., a third-degree polynomial within each interval) was employed to account for nonlinearities in the Federal Reserve reaction function. In the absence of a priori knowledge of the precise functional form, the cubic form was chosen because it provides substantial flexibility in the form of the function without increasing excessively the number of parameters to be estimated. For this reason, the cubic spline has been the most widely used form in empirical work [see, for example, Barth, Kraft and Kraft (1976), Buse and Lim (1977) and Poirier (1973)]. Spline function estimates are provided for one, two, and three intervals specified over the independent variables. No theoretical reasons exist for setting the number of subintervals, but three are sufficient to provide information as to whether or not the severity of economic conditions influences Federal Reserve behavior. Insofar as there are no a priori reasons for selecting particular knot values, the ranges for the intervals were selected by an entropy rule. This suggests that in the absence of any reasonable prior distribution, the uniform is the least offensive to use. Thus, the size of each interval is given by $(Z_{0,max} - Z_{0,min})/m$, $m = 1, 2, 3$.[11]

The most general specification of the spline function (assuming non-stochastic parameters) may be written as follows:

$$Y = g[A(L)Z_0] + B(L)Z_1 + U\,, \tag{2}$$

where Y and U are $(Tx1)$ vectors of observations on the dependent variable and disturbance term, with $U \sim N(0,\sigma^2\Omega)$, g is a continuous function which is differentiable up to an arbitrary degree, and $A(L)$ and $B(L)$ are lag operators on Z_0 and Z_1; Z_0 is a $(Tx1)$ vector of the policy objective variable splined, and Z_1 is a (TxK) matrix of other

[11]It should be noted that the degree of the polynomial, the number of switching points (knots), and the values of the knots are parameters that can, in principle, be estimated, given the appropriate likelihood function. However, the use of a maximum likelihood function approach to the simultaneous estimation of the above parameters is a topic for further research. See Gallant and Fuller (1973).

explanatory variables. By letting c, the four-month moving average of the independent variable of the spline function, equal $A(L)Z_0$ and ignoring time subscripts, the generalized cubic spline function for the three-interval model can be written as

$$g(c) = D_1 g_1(c) + D_2 g_2(c) + D_3 g_3(c) , \tag{3}$$

where

$$g_i(c) = \alpha_{i,1} + \alpha_{i,2}c + \alpha_{i,3}c^2 + \alpha_{i,4}c^3 ,$$

$$D_1 = \begin{cases} 1 \text{ if } c < c_1 \\ 0 \text{ otherwise} \end{cases} ; \quad D_2 = \begin{cases} 1 \text{ if } c_1 < c < c_2 \\ 0 \text{ otherwise} \end{cases} ; \quad D_3 = \begin{cases} 1 \text{ if } c > c_2 \\ 0 \text{ otherwise} \end{cases} ,$$

and c_1 and c_2 are the knots.

The following restrictions are imposed:

$$g_i(c_i) = g_{i+1}(c_i) \tag{3.1}$$

$$g_i'(c_i) = g_{i+1}'(c_i) \tag{3.2}$$

$$g_i''(c_i) = g_{i+1}''(c_i) . \tag{3.3}$$

These restrictions assure that the cubic polynomials are joined at the knots (the c_i's) and hence that the entire function $g(c)$ is continuous, that the slopes of the $g_i(c)$'s are equal at the knots, and that the curvatures of the $g_i(c)$'s are equal at the knots. It should be noted that equation (2) can also be estimated without these restrictions as long as the number of observations in each interval is greater than or equal to four.

Buse and Lim (1977) have noted that the model described by equations (2) and (3), and the restrictions of (3.1)—(3.3) can be represented in a more compact form as:

$$Y = X\beta + \epsilon , \quad \text{S.T.} \quad R\beta = r , \tag{4}$$

where $\epsilon \sim N(0,\sigma^2\Omega)$. The generalized spline estimator and its covariance matrix are thus given by:

$$\overset{\Delta}{\beta} = \tilde{\beta} + (x'\Omega^{-1}x)^{-1}R'[R(x'\Omega^{-1}x)^{-1}R']^{-1}(r - R\tilde{\beta}) , \tag{5}$$

and

$$\operatorname{cov}(\overset{\Delta}{\beta}) = \sigma^2 A(x'\Omega^{-1}x)^{-1}, \tag{6}$$

where

$$\tilde{\beta} = (x'\Omega^{-1}x)^{-1} x'\Omega^{-1}y,$$

and

$$A = I - (x'\Omega^{-1}x)^{-1}R'[R(x'\Omega^{-1}x)^{-1}R']^{-1}R.$$

3. Empirical Results

The data used in this study consist of a time series of monthly observations for the period January 1953 through February 1978. Values for the inflation rate, (*P*), measured as the annualized monthly percentage change in the Consumer Price Index; for the unemployment rate (*U*); for total sales (*TS*); and for the interest rate (*r*), as measured by the three-month Treasury bill rate, were obtained from various issues of the *Survey of Current Business* and from *Business Conditions,* 1971. Monthly data for the full-employment federal budget surplus (*FES*) were obtained by interpolating the quarterly series published by the Federal Reserve Bank of St. Louis. Values for the inflation rate varied from −1.5 to 12.7 percent over the period, with knot values of 3, 2, and 7.9 percent. The values for the unemployment rate varied from 2.6 to 8.9 percent, with knot values of 4.7 and 6.8 percent.

All variables are represented as deviations from their mean values. Forcing the relationship through the origin is necessary in order to identify the constant terms of the piecewise cubic polynomials on which the above restrictions are imposed. It should be noted that a double spline [Suits, *et al.* (1978)] or a more complicated interactive specification that Poirier refers to as the "bilinear spline" [Poirier (1975)] could be estimated within the framework of the generalized least-squares estimator under linear constraints. However, this would force one to require that the additional splined polynomials not have constant terms (otherwise $X'X$ would become singular). Furthermore, since the number of parameters within each interval would be reduced to three, the three sets of restrictions on the parameters would have to be reduced in number as well, otherwise the restriction would force the parameters in

each of the intervals to be the same.[12] Thus one would have to alter the parameterization of $g_i(c)$ above as well as of the restrictions.

The estimates for several parameterizations of the reaction function are presented below. All are nested in the Generalized Spline Estimator. A first-order autoregressive disturbance structure was assumed and the autoregressive parameter was estimated using an iterative Prais-Winsten procedure.[13]

Initially, an equation was specified in which all independent variables enter in linear form.[14] The generalized least-squares (*GLS*) estimates for this equation are reported in the first column of Table 1. In the next parameterization the constraint $\alpha_{ij} = \alpha_{kl}(i,k = 1,3; j,l = 1,4)$ is imposed, which yields a cubic polynomial in one ultimate policy objective variable over the entire range of values. This constraint eliminates the classification of subintervals for the independent variable. The *GLS* estimates for these conventional cubic equations for both unemployment and inflation are reported in the second and third columns, respectively, of Table 1. Finally, a comparable set of results for the estimation of equations (4) and (5) using the generalized spline estimator without the above restrictions is presented in Table 2. Columns 1 and 2 report the results

[12]Assume for simplicity that

$$y = D_1 f_1(x) + D_2 f_2(x) ,$$

where

$$f_1(x) = b_1 x + b_2 x^2 , \quad D_1 \begin{cases} 1 \text{ if } x < x_0 \\ 0 \text{ otherwise} \end{cases}$$

$$f_2(x) = b_3 x + b_4 x^2 , \quad D_2 \begin{cases} 1 \text{ if } x > x_0 \\ 0 \text{ otherwise} \end{cases}$$

and

$$f_1(x_0) = f_2(x_0) ,$$

$$f_1'(x_0) = f_2'(x_0) .$$

These restrictions are satisfied iff $b_1 = b_3$ and $b_2 = b_4$.

[13]See Maeshiro (1976, 1979).

[14]As can be noted from the formal model above, linear as well as the simple cubic functions can be viewed as special cases of the more general cubic spline function in which restrictions are imposed on the values of some of the coefficients.

TABLE 1. *Reaction Function Estimates: Linear and Cubic Form, Dependent Variable—Monetary Base*

Independent Variable	*Linear*	*Cubic on U*	*Cubic on P*
Constant	—	−28.331	54.570
		(−0.057)	(0.141)
TS	0.599*	0.613*	0.624*
	(51.16)	(58.491)	(70.305)
Δr	−297.236	−330.138	−301.961
	(−1.482)	(−1.622)	(−1.460)
FES	−0.050*	−0.046*	−0.051*
	(−4.74)	(−3.851)	(−4.799)
U	917.209*	834.443*	882.698*
	(7.49)	(5.249)	(7.292)
U^2	—	77.682	—
		(1.373)	
U^3	—	1.124	—
		(0.053)	
P	−57.051*	−53.339*	−68.398*
	(−3.00)	(−2.707)	(−2.836)
P^2	—	—	−9.626*
			(−2.558)
P^3	—	—	0.743*
			(2.225)
$\bar{R}^2$	0.898	0.925	0.947
D.W.	1.969	1.954	1.931

Numbers in parentheses represent *t*-statistics; *indicates coefficient is significant at the five percent level.

where the unemployment rate is partitioned into two and three intervals, respectively, with different cubic functions estimated for each interval. All other explanatory variables enter linearly. The results for the equations when the inflation rate is similarly partitioned into two and three intervals appear in columns 3 and 4. The following discussion focuses primarily on the most detailed specifications, the three-interval spline estimates, and draws comparisons with the other results reported.

TABLE 2. *Reaction Function Estimates: Cubic Spline Form with Two and Three Intervals on Inflation Rate and Unemployment Rate, Dependent Variable—Monetary Base*

Independent Variable	*Spline on U 2 Interval*	*Spline on U 3 Interval*	*Independent Variable*	*Spline on $\mathring{P}$ 2 Interval*	*Spline on $\mathring{P}$ 3 Interval*
TS	0.613*	0.617*	*TS*	0.639*	0.640*
	(59.690)	(61.767)		(99.933)	(101.392)
Δr	−339.570	−336.947	Δr	−350.791	−345.312
	(−1.664)	(−1.644)		(−1.627)	(−1.579)
FES	−0.053*	−0.050*	*FES*	−0.061*	−0.063*
	(−4.069)	(−3.581)		(−5.754)	(−5.821)
$\mathring{P}$	−50.580*	−53.115*	*U*	652.506*	639.171*
	(−2.547)	(−2.638)		(5.760)	(5.645)
		Lower Interval			
K_1	−122.403	−203.758	K_1	29.211	7.127
	(−0.255)	(−0.445)		(0.124)	(0.031)
U_1	689.408*	998.571*	$\mathring{P}_1$	27.656	9.033
	(3.582)	(4.182)		(0.860)	(0.296)
U_1^2	159.470	684.049	$\mathring{P}_1^2$	−13.869*	−13.726
	(1.876)	(1.772)		(−3.414)	(−0.927)
U_1^3	62.436	226.714	$\mathring{P}_1^3$	−3.761*	−3.144
	(1.191)	(1.654)		(−3.517)	(−1.251)
		Middle Interval			
K_2	—	−232.598	K_2	—	7.143
		(−0.504)			(0.031)
U_2	—	810.676*	$\mathring{P}_2$	—	9.272
		(4.402)			(0.304)
U_2^2	—	275.562*	$\mathring{P}_2^2$	—	−12.527
		(2.076)			(−1.000)
U_2^3	—	−69.149	$\mathring{P}_2^3$	—	−1.146
		(−1.058)			(−0.656)
		Upper Interval			
K_3	−96.936	−604.436	k_3	−48.240	−607.006
	(−0.202)	(−0.587)		(−0.205)	(−1.518)
U_3	557.060*	1501.491	$\mathring{P}_3$	134.723*	415.064*
	(2.102)	(0.861)		(2.639)	(1.962)
U_3^2	388.733	−152.246	$\mathring{P}_3^2$	−63.205*	−101.901*
	(1.559)	(−0.158)		(−4.918)	(−2.931)
U_3^3	−69.946	19.162	$\mathring{P}_3^3$	3.817*	5.415*
	(−1.174)	(0.120)		(4.810)	(3.263)
$\bar{R}^2$	0.930	0.935	$\bar{R}^2$	0.977	0.978
D.W.	1.955	1.948	*D.W.*	1.759	1.730

U_i^j = unemployment rate within the *i*th interval, raised to the *j*th power; $\mathring{P}_i^j$ = inflation rate within the *i*th interval, raised to the *j*th power; K_i = intercept (constant) term in the *i*th interval. Numbers in parentheses represent *t*-statistics; *indicates coefficient is significant at the five percent level.

In the equation for the three-interval spline estimate on the unemployment rate, the coefficients on *TS*, *FES*, and *P*, which enter linearly, are significant with the hypothesized signs: positive, negative, and negative, respectively. The coefficient on Δr is not significant and carries a negative rather than the hypothesized positive sign. These results are essentially the same as for the other specifications of the reaction function reported in Table 1. The coefficients on the linear unemployment rate terms are significant in the lower two intervals. The squared unemployment term is significant at the five-percent level only in the second interval but is also significant in the lower interval at the ten-percent level. None of the cubic terms and none of the coefficients in the upper interval are significant. This suggests a quadratic response of the Federal Reserve over the lower two intervals, which is consistent with the results of the two-interval spline estimates. However, the response is less systematic when the unemployment rate is in the highest range. This finding of a lack of significance at high unemployment rates was not obtainable from the other specifications of the reaction function.

Although these parameter estimates provide considerable information concerning the form of the reaction function within each interval, a better understanding of the Federal Reserve's response to the unemployment rates requires an examination of the elasticity of the monetary base with respect to the unemployment rate. These values are calculated based upon the estimated parameters and the mean values of the variables within each subinterval and are reported in Table 3.

TABLE 3. *Estimates of the Elasticity of the Monetary Base with Respect to the Unemployment Rate: Cubic and Cubic Spline Forms**

Range of U	*Cubic Form 1 Interval*	*Cubic Spline 2 Intervals*	*Cubic Spline 3 Intervals*
Lower	0.079	0.045	0.080
Middle	0.080	—	0.091
Upper	0.100	0.114	0.080

*Elasticity estimates were computed at mean values of *U* and *B* within each interval. Although the equation for column 1 was estimated as a single cubic equation over the entire range of *U* values (i.e., no sub-intervals specified), elasticity estimates were computed at mean values of each sub-interval of the three-interval spline function for comparison to the spline results.

Elasticity estimates for the three-interval spline have the expected positive sign and are quite similar to those obtained from the one- and two-interval cases. Notable is the similarity in elasticity values between intervals. It appears that the Federal Reserve responds somewhat uniformly to unemployment rate changes regardless of the level of the rate, or the severity of the unemployment problem. In light of these results and of the generally insignificant coefficients on the nonlinear unemployment rate terms, it is not surprising that other studies specifying a less general form of the reaction function found a significant response by the Federal Reserve to the unemployment rate [see, for example, Froyen (1974)].

Turning to the results obtained when the inflation rate is splined and partitioned into three intervals, it is found that the linear unemployment rate term carries the expected positive and significant sign as is the case for the simple linear and cubic equations. Two other variables, *TS* and *FES*, also carry the expected signs and are significant as before. The interest rate coefficient has the wrong but insignificant sign as in the other functional forms. In general, the coefficients of the variables that enter this equation only in linear form are not substantially different from those reported for the strictly linear equation. The coefficients on the inflation rate terms in the lower and middle interval are not significant, while those in the upper interval are significant. Although this finding raises doubts about a systematic response at lower inflation rates, it supports the view that the Federal Reserve reacts to inflation rate changes only when inflation is most severe. It also supports the hypothesis that the response is nonlinear, even within this upper range. It should be noted that, in contrast, all coefficients on the inflation terms on the one-interval cubic form are significant. The cubic spline results show, however, that this finding is due to a failure to take into account the severity of inflation.

Table 4 contains the elasticity estimates for the response of the monetary base to the inflation rate. Estimates were computed for each cubic form and for each subinterval as before. All estimates have the anticipated negative sign with the exception of the elasticity coefficient for the lower range of the three-interval spline estimate. However, this elasticity is very small and the coefficient estimates from which it was computed are not significant. A small and insignificant response to a change in the inflation rate during a period of stable prices (or low inflation rates) is not a surprising result and suggests possibly greater concern with other economic conditions during these times.

TABLE 4. *Estimates of the Elasticity of the Monetary Base with Respect to the Inflation Rate: Cubic and Cubic Spline Forms**

Range of P	*Cubic Form 1 Interval*	*Cubic Spline 2 Intervals*	*Cubic Spline 3 Intervals*
Lower	−0.004	−0.002	0.001
Middle	−0.006		−0.003
Upper	−0.011	−0.020	−0.129

*Elasticity estimates were computed at mean values of P and B. As in Table 3, estimates in column 1, the simple cubic form, are computed at the mean values for each of three subintervals for comparison to the spline results.

Of note, however, is the substantially larger elasticity estimate in the upper range of the three-interval spline function, indicating a pronounced increase in the responsiveness of the Federal Reserve to the inflation rate when inflation is most severe. These results suggest that the Federal Reserve responds systematically to inflation rate changes only when the inflation rate is high. When it does respond, however, it does so decisively. Much instability in the economy, including the rather severe recession of 1974–75 and the sharp downturn in the first half of 1980, has been attributed by some observers to the strong reactions of the Federal Reserve. Our findings are not inconsistent with this view.

4. Comparison with Previous Studies

A summary of the results of major previous studies is reported in Table 5. Due to the differences in the intent and the interpretation of the studies, and especially due to the differences in the choice of the dependent (or instrument) variable, of explanatory variables, and of functional forms, any such summary omits important details. However, Table 5 conveys information as to the general form of the equations tested and the results found in these studies. The studies are presented in chronological order. The signs in the table refer to the coefficients on variables included in the equation with a significant positive effect (+) on the policy instrument, a significant negative effect (−), or no significant effect (0).

GLOSSARY OF SYMBOLS:

U = Unemployment Rate;
$\dot{P}$ = Inflation rate or the absolute change in price index;

BPS = Balance of payments surplus;
Y/P = Real income, (in Potts—Luckett, an Industrial Production Index was used);
Y = Nominal income;
TS = Total sales, generally specified as business sales;
XR = Exchange rate;
D = Outstanding U.S. government debt in the hands of the public;
r = Short-term interest rate, (specifications included the treasury bill rate and the federal funds rate, and enter lagged in level form or in first differences);
FES = Full-employment federal government budget surplus;
M = Monetary aggregate, (alternatively specified as money supply, monetary base, bank reserves, and bank credit proxy in various studies);
Gap = Difference between desired and actual output ($Y_d - Y_a$).

These results show that the unemployment rate was significant and exhibited the expected sign more frequently than was the case with the inflation rate. A more careful examination of the studies also shows that it was generally concluded that the Federal Reserve's response to changes in the unemployment rate was greater than its response to inflation rate changes. Each of the studies that estimated a reaction function over time periods corresponding to different Presidential Administrations [Froyen (1974) and Potts—Luckett (1978)] found the inflation rate to be significant only in one Administration. However, a significant response to changes in the unemployment rate was found in different Administrations.

Two other studies examined the effect of economic conditions on the behavior of the Federal Reserve. The study by Havrilesky, Sapp and Schweitzer (1975) found a systematic response of the federal funds rate to inflation during periods the authors classified as "tight" money periods and to unemployment during "easy" money periods. However, only in the study by Christian (1968) was the effect of the severity of inflation and unemployment and the possibility of a nonlinear response noted. This particular study used a moving regression technique over twenty-quarter periods to examine the stability of the response over time. The results indicated a more systematic and larger response to inflation and unemployment during periods when these variables were at relatively high levels, or during the ". . . period of concern . . ." over these vari-

ables.[15] This was especially true in the case of the inflation variable. Although these results are in part consistent with those reported here, Christian never tested explicitly for nonlinearity either over the entire period or within periods of high inflation. This earlier study also did not cover the recent decade of persistent price instability.

As was the case in our study, most previous studies that included a nominal income or sales variable to account for actions taken by the Federal Reserve to accommodate the needs of trade produced a positive and significant coefficient for this variable. However, the only other study (Froyen, 1974) which included *FES* to account for actions taken by the Federal Reserve to coordinate monetary and fiscal policies yielded a significant coefficient only for selected time periods. This finding is consistent with the results of our study. The only variable that was consistently insignificant in our study was Δr. In only the Teigen study (Teigen, 1969) was this variable significant, and this result was interpreted as due to the Federal Reserve's concern with capital flows.[16]

5. Summary and Conclusions

This study has estimated a Federal Reserve reaction function that allows for the possibility that the marginal response of the Federal Reserve depends upon the severity of inflation and unemployment. A Generalized Spline Estimator was developed to determine whether or not this is indeed the case. Alternative cubic spline estimates were obtained by partitioning the values of the objective variables into one, two, and three subintervals. In general, the results suggest that the monetary base is adjusted in the expected direction with both of these variables, positively to unemployment and negatively to inflation. Furthermore, the results indicate that the response is indeed nonlinear and varying with the severity of economic conditions, especially in the case of the inflation rate.

More specifically, it was found that the Federal Reserve has adjusted the monetary base positively in response to the unem-

[15]Christian (1968), p. 471.

[16]Because most previous studies did not find a significant response to the balance of payments surplus, this variable was not included in our study. However, future work might consider employing a spline function to reconsider the importance of international financial conditions in influencing Federal Reserve behavior.

TABLE 5. *Summary of Previous Estimates of Monetary Policy*

Study	*Time Period*	*Dependent Variable*	*Form*
Dewald-Johnson (1963)[a]	1952:i–1961:iv	Money Supply (M1)	Level
Goldfeld (1966)[a]	1950:iii–1962:ii	Potential Demand Deposits	Level
Havrilesky (1967)[a]	1952:ii–1965:iv	Total Reserves	Level
Wood (1967)[a]	1952:i–1963:iv	Fed Holdings of Gov't. Securities	Change
Christian (1968)	1952:i–1966:iv	Money Supply (M1)	Change
		Free Reserves	[d]
	1952:i–1966:iv	Treasury Bill Rate	
Teigen (1969)[a]	1953:i–1964:iv	Unborrowed Reserves & Currency	Percent Change
Froyen (1974)	1953:2–1961:1	Monetary Base	Level
	1961:2 1969:1	Monetary Base	Level
	1969:2–1972:12	Monetary Base	Level
	1964:1–1974:2[e]	Monetary Base	Level
Havrilesky, Sapp, and Schweitzer (1975)	Easy Money Periods	Federal Funds Rate	Percent Change
	Tight Money Periods	Federal Funds Rate	Percent Change
DeRosa-Stern (1977)	1967:3–1969:12	Federal Funds Rate	Percent Change
	1970:12–1974:12	Federal Funds Rate	Percent Change
Chase Econometrics (1978)	1966:1–1970:2	Federal Funds Rate	Change
	1970:3–1978:1	Federal Funds Rate	Change
Potts-Luckett (1978)	1956:1–1975:12	Tight Money vs Easy Money	Discriminant Analysis
	1956:1–1961:1	Tight Money vs Easy Money	Discriminant Analysis
	1961:2–1969:1	Tight Money vs Easy Money	Discriminant Analysis
	1969:2–1975:12	Tight Money vs Easy Money	Discriminant Analysis
Abrams, Froyen, and Waud (1978)	1970:3–1977:3	Federal Funds Rate	Level

Notes: + = positive significant sign, − = negative significant sign, 0 = insignificant sign on coefficient at the 5% level. For frequency of data, Q means Quarterly, M means monthly data.

[a]Summaries of these studies were obtained from Froyen (1974).

[b]Although measures of the balance of payments were not significant, a significant sign on a vector of foreign interest rates indicated sensitivity to capital flows.

[c]The sensitivity to *r* (treasury bill rate) was interpreted as sensitivity to potential capital flows.

Reaction Functions

Data Frequency	*U*	*P*	*BPS*	*Y/P*	*Y*	*TS*	*XR*	*D*	*r*	*FES*	*M*	*Gap*
Q	+	0	0		+							
Q	+	0	0		+							
Q	+	−	0[b]		+							
Q	0	0	+	−								
Q	+	−	+		+							
Q	0	−	0									+
Q	0	+	0									−
Q	0	0	0[c]		+				+[c]			
M	+	0	0			+		0	0	0		
M	+	−	0			+		+	0	−		
M	+	0	+			+		0	0	0		
M												
M	−	±[f]					+					
M	0	+					+					
M						0			+		0	
M						+			0		+	
M	−	0									0	
M	−	+									+	
M	−	0	0	+								
M	0	+	0	+								
M	−	0[g]	0	+								
M	−	0	0	0[g]								
M	−	+[h]				+	+				+	

[d]Twenty-period moving regressions were used to examine stability of coefficients over time. Results suggest reaction is unstable over time. Christian suggests this may indicate the influence of the severity of condition and/or a nonlinear response.

[e]Six successive sub-periods were examined indicating alternating easy money and tight money periods. The two periods here represent composite results of these two types of economic conditions. The results suggest that the reaction differs.

[f]This coefficient changed in sign in different easy money periods.

[g]Significant at the ten percent level, with the expected positive signs.

[h]Significant in only one of the equations estimated, the simplest form in which monetary aggregate (monetary base) and exchange rate variables were omitted.

ployment rate. In the most detailed equation, the three-interval cubic spline, significant coefficients were found in the lower and middle ranges for unemployment; but no significance was found in the upper range. This suggests that the level, or severity, of unemployment does have an impact on the marginal response of the monetary base to unemployment rate changes, though the response tends to be less systematic during periods of relatively high unemployment. This is a finding which earlier studies were unable to detect. Further examination of elasticity estimates of this relationship reveals that the percentage responses are relatively stable across intervals. The rather uniform responsiveness of the Federal Reserve suggests a relatively consistent policy toward unemployment with the notable exception of high unemployment rate periods.

There was strong evidence of a nonlinar response of the monetary base to inflation. In both the one and two interval specifications, all coefficients on nonlinear terms were significant. In the three interval specification, only the coefficients in the upper interval were significant. This suggests that the Federal Reserve adjusts the monetary base nonlinearly to changes in the inflation rate and that the response is systematic only in the upper range when inflation is most severe. Elasticity estimates indicate that the percentage response is also substantially greater in the upper interval.

Previous studies frequently concluded that the Federal Reserve responds systematically to the unemployment rate but that a lower priority was generally placed on the inflation rate. However, the failure to account for nonlinearity and severity effects in this response may have caused other researchers to underestimate the significance and the importance of inflation as a determinant of Federal Reserve behavior. Several other recent studies have noted structural shifts over time in the reaction function and have attributed these apparent shifts to political factors including which Presidential Administration is in office at the time and how related political priorities are ordered [as in Froyen (1974) and Potts and Luckett (1978)], or to a change in the operating procedures or operating targets of the Federal Reserve itself, as in Chase Econometrics (1978). However, these studies generally did not examine the extent to which shifts may be caused by the severity of inflation and unemployment. The results of this paper suggest that this factor has had a substantial influence on Federal Reserve behavior and may provide an alternative explanation of the apparent shifts in monetary policy over time.

One implication of our results concerns the appropriateness of specifying a linear Federal Reserve reaction function. It appears that the nonlinearity of the Federal Reserve's response and the effect of the severity of economic conditions, especially as regards the inflation rate, may limit the reliability of estimates based on a linear specification. This result also raises questions about the validity of assuming a quadratic loss function as the objective function of the Federal Reserve. Because the coefficients in the reaction function are determined jointly by the form of the objective function and by the Federal Reserve's perception of the impact of its policy actions, a nonlinear reaction function implies an objective function more complex than the quadratic loss function and/or a perception that policy actions have a nonlinear impact on inflation and unemployment.[17] This issue deserves further attention.

Another important implication of the results arises from the importance of the reaction function in the formation of the public's expectations and the resulting impact of expectations on the effectiveness of monetary policy. The significance of the effects of unemployment, inflation, and the additional variables capturing the accommodative behavior (the full-employment budget surplus and total sales) suggests a systematic response of the Federal Reserve. If this behavior is recognized and used by the public in forming expectations, the strict rational expectations hypothesis suggests that monetary policy may not be effective in altering real economic activity. When testing this proposition, the use of a linear reaction function instead of a more general function as suggested in this paper may produce misleading results due to the inaccurate assessment of anticipated and unanticipated components of monetary policy. In addition, the apparent complexity of the reaction function, even if relatively stable in the cubic spline form, may imply that costs are sufficiently high to preclude the public from acquiring complete knowledge of it so that deliberate and systematic monetary policy actions may influence real activity. Certainly tests of rational expectations models should more fully examine the form of the reaction function. More importantly, an attempt should be made to reconcile our finding that the Federal Reserve responds to the unemployment rate with the rationality of the Federal Reserve within the context of the rational expectations hypothesis; for it appears that the Federal Reserve responds to the unemployment

[17]See Wood (1967) for a discussion of the theoretical derivation of the reaction function.

rate but is powerless to deliberately and systematically affect this rate.

In sum, using a Generalized Spline Estimator it was found that the monetary authority's reaction to the inflation rate depends upon its severity, with a similar but less strong effect also evident for the unemployment rate. These results suggest that more careful attention should be given to the specific functional form employed in the estimation of a Federal Reserve reaction function, whether individually or as part of a larger macroeconomic model, particularly when attempting to distinguish between anticipated and unanticipated movements in policy variables.

Received: April, 1980
Final version received: August, 1981

References

Abrams, Richard, Richard Froyen and Roger Waud. "Monetary Reaction Functions, Consistent Expectations, and the Burns Era." *Journal of Money, Credit and Banking* 12 (February 1980): 30–42.

Barth, James, Arthur Kraft and John Kraft. "Estimation of the Liquidity Trap Using Spline Functions." *Review of Economics and Statistics* 58 (May 1976): 218–22.

Buse, Adolf and Liat Lim. "Cubic Splines as a Special Case of Restricted Least Squares." *Journal of the American Statistical Association* 72 (March 1977): 64–68.

Chase Econometrics. "Financial Forecasts: Executive Summary." (June 20, 1978): 10–17.

Christian, James W. "A Further Analysis of the Objectives of American Monetary Policy." *Journal of Finance* 23 (May 1968): 465–77.

Corradi, C. and G. Gambetta. "The Estimation of Distributed Lags by Spline Functions." *Empirical Economics* 3 (1977): 68–75.

DeRosa, Paul and Gary H. Stern. "Monetary Control and the Federal Funds Rate." *Journal of Monetary Economics* 3 (April 1977): 217–30.

Dewald, William B. and Harry G. Johnson. "An Objective Analysis of the Objectives of Monetary Policy." In *Banking and Monetary Studies*. D. Carson, ed. Homewood, IL: Irwin, 1963, 171–89.

Fisher, Douglas. "The Objectives of British Monetary Policy: 1951–1964." *Journal of Finance* 23 (June 1968): 821–31.

Froyen, Richard T. "A Test of the Endogeneity of Monetary Policy." *Journal of Econometrics* 2 (July 1964): 175–88.

Gallant, A. R. and Wayne A. Fuller. "Fitting Segmented Polynomial Regression Models Whose Joint Points Have to be Estimated." *Journal of the American Statistical Association* 68 (March 1973): 144–47.

Goldfeld, Stephen M. and Alan S. Blinder. "Some Implications of Endogenous Stabilization Policy." *Brookings Papers on Economic Activity* 3 (1972): 585–640.

———. *Commercial Bank Behavior.* Amsterdam: North Holland, 1966.

Havrilesky, Thomas. "A Test of Monetary Policy." *Journal of Political Economy* 75 (June 1967): 299–304.

———, Robert H. Sapp and Robert L. Schweitzer. "Tests of the Federal Reserve's Reaction to the State of the Economy." *Social Science Quarterly* 55 (March 1975): 835–52.

Keran, Michael W. and C.T. Babb. "An Explanation of Federal Reserve Actions (1933–68)." *St. Louis Federal Reserve Bank Review* 51 (July 1969): 7–20.

Maeshiro, Asatoshi. "On the Retention of the First Observations in Serial Correlation Adjustment of Regression Models." *International Economic Review* 20 (February 1979): 259–66.

Poirier, Dale J. "Piecewise Regression Using Cubic Splines." *Journal of the American Statistical Association* 68 (September 1973): 515–24.

———. "On the Use of Bilinear Splines in Economics." *Journal of Econometrics* 3 (February 1975): 23–34.

Potts, Glenn T. and Dudley G. Luckett. "Policy Objectives of the Federal Reserve System." *The Quarterly Journal of Economics* 92 (August 1978): 525–34.

Suits, Daniel B., Andrew Mason and Louis Chan. "Spline Functions Fitted by Standard Regression Methods." *Review of Economics and Statistics* 60 (February 1978): 132–39.

Swamy, P.A.V.B., James R. Barth and Peter A. Tinsley. "The Rational Expectations Approach to Economic Modelling." Special Studies Paper #143, Federal Reserve Board, July 1980, and the *Journal of Economic Dynamics and Control,* forthcoming.

Teigen, Ronald L. "An Aggregate Quarterly Model of the U.S. Monetary Sector, 1953–1964." In *Targets and Indicators of Monetary Policy.* K. Brunner, ed. San Francisco: Chandler, 1969, 175–218.

Theil, Henri. *Principles of Econometrics*. New York: John Wiley and Sons, 1971.

Wood, John H. "A Model of Federal Reserve Behavior." In *Monetary Process and Policy: A Symposium*. G. Horwich, ed. Homewood, IL: Irwin, 1967, 135–66.