Monetary policy and stability during six periods in US economic history: 1959-2008: a novel, nonlinear monetary policy rule

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A nonlinear monetary policy rule

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Abstract

We investigate the monetary policy of the Federal Reserve Board during six periods in US economic history 1959-2008. In particular, we examine the Fed's response to changes in three guiding variables: inflation, π, unemployment, U, and industrial production, y, during periods with low and high economic stability. We identify separate responses for the Fed's change in interest rate depending upon i) the current rate, FF, and the guiding variables' level below or above their average values, ii) recent movements in inflation and unemployment. The change in rate, ΔFF, can then be calculated. We identify policies that both increased and decreased economic stability.

Key words

Monetary policy rule; economic stability, Taylor rule, nonlinear methods, USA

INTRODUCTION

We explore the role of monetary policy on the stability of business cycling during six periods in US economic history from 1959 to 2008. We examine in particular the Federal Reserve's response to three candidate target, or guiding, variables: inflation, industrial production and unemployment. The first two correspond to the guiding variables in the Taylor rule (1993; Doran and Hickey 2009). We develop a nonlinear (compass –type) policy reaction function in which the reaction coefficients depends upon movements in both FF and the explanatory variable and how the movements relate to their average values. The method is based upon the assumption that the chosen candidate explanatory variables are sufficient to explain differences in economic volatility among periods.

The Taylor rule is currently debated (2012) because of its role during the current recession both in the US and the EU. (Giammarioli and Valla 2004; Fourcans and Vranceanu 2007; Rudebusch 2009; Fernandez et al. 2010; Cancelo et al. 2011). Recently, nonlinear Taylor rule functions have been discussed by Taylor and Davradakis (2006), Aksoy et al. (2006), Orphanides and Wieland (2008) and Hayat and Mishra (2010). Below, we give our working version of the Taylor rule, e.g., (Taylor 2009), and then we discuss Okun's law that links unemployment to output (GDP). The latter rule helps explain why a response to output may be confounded with a response to unemployment.

The Taylor rule in its original formulation states how much the central bank should change the nominal interest rate, in US, a federal funds rate, i, in response to the difference between actual inflation π_t and the target inflation, π^*, and to the actual output, GDP, from the potential output GDP. The output parameters y_t and y_t^* are defined as the logarithm of the GDPs:

$$i_t = r^* + \pi^* + \beta_\pi(\pi_t - \pi^*) + \beta_y\left(100 \times \frac{y_t - y_t^*}{y_t^*}\right) \quad . \qquad (1)$$

Here r^* is the equilibrium real interest rate corresponding to the potential GDP. $r^* + \pi^*$ is the long-term equilibrium interest rate. According to the rule, both β_π and β_y should be positive. Taylor (1993) proposed the values $\beta_\pi = 1.5$ and $\beta_y = 0.5$. Clarida et al (2000) showed that during the highly volatile pre-Volcker era $0 < \beta_\pi < 1$, and in the much more stable post-Volcker era (from 1982) the slope β_π was >> 1 (pre- and post aggregate volatility indicators were 2.77 and 1.00 respectively.) Rudebusch (2006) found that $\beta_\pi = 1.39$ and $\beta_y = 0.92$ for the period 1988- 2005 with least squares regression. Hayat and Mishra (2010) found that the

β_π – coefficient would be zero at less than 6.5 – 8.5% changes in inflation, independent of period.

Okun's law states that the gross domestic product, y_t, is negatively related to unemployment, u:

$$\frac{y-y^*}{y^*} = -\omega(u - u^*) \qquad (2)$$

Okun's law is reported to show a consistent negative correlation where ω is about 2, as summarized by Dornbusch et al. (2008).

We construct phase plots for the variables (one variable on the x-axis and the other variable on the y-axis, Figure 1 lower panels). For 6 variables there will be 15 such pairs. These phase plots describe graphically the relationship between paired variables. The relationship is formally quantified by calculating the slopes $v_{i,i+1}$ for the trajectories between sequential states i and i+1 and the x-axis. We also determine if the initial values of the trajectories are below or above the average value of the variables, and we determine from which of six historic periods the observations were taken. We thereafter calculate a measure of the stability of business cycles during the six periods. This allows us to examine which moves were characteristic during periods with low or high stability. The technical method is called the angle frequency method, AFM, (Sandvik et al. 2004), and to our knowledge it is the only method that allows detection of cyclical or spiraling movements in phase plots , e.g., Brunnermeier (2009, Fig 9) for spiraling effects in an economy.

The trajectory angles and their interpretation in economics. To give a rationale for the AFM, we show how the trajectory angles can be interpreted in economic terms. For illustration purposes, we assume that the business cycles are represented by perfect sines, Figure 1a.

Observed cycles can be looked upon as sine curves with added noise. The upper two panels show a target variable (a1 and b1) and an alternative series that is shifted in time relative to the target. The two lower panels show the phase plots corresponding to the time series in the upper panels. The alternative variable may relate to the target variable by being coincident (a), leading, counter cyclic, or lagging (b). It is seen that the phase plots in the lower two panels give signatures of the relationship between the paired variables. Variables that are coinciding, for example variables that belong to National Bureau of Economic Research's, NBER's, coinciding indicator, would show a pattern like the ones in a) and c). This means that the angle $v_{i,i+1}$ in the phase plots for the trajectory from i to i+1 will be around 45° or 225° whether the trajectory starts below or above average values of the two variables, and most of the trajectories will start in quadrant I or III.

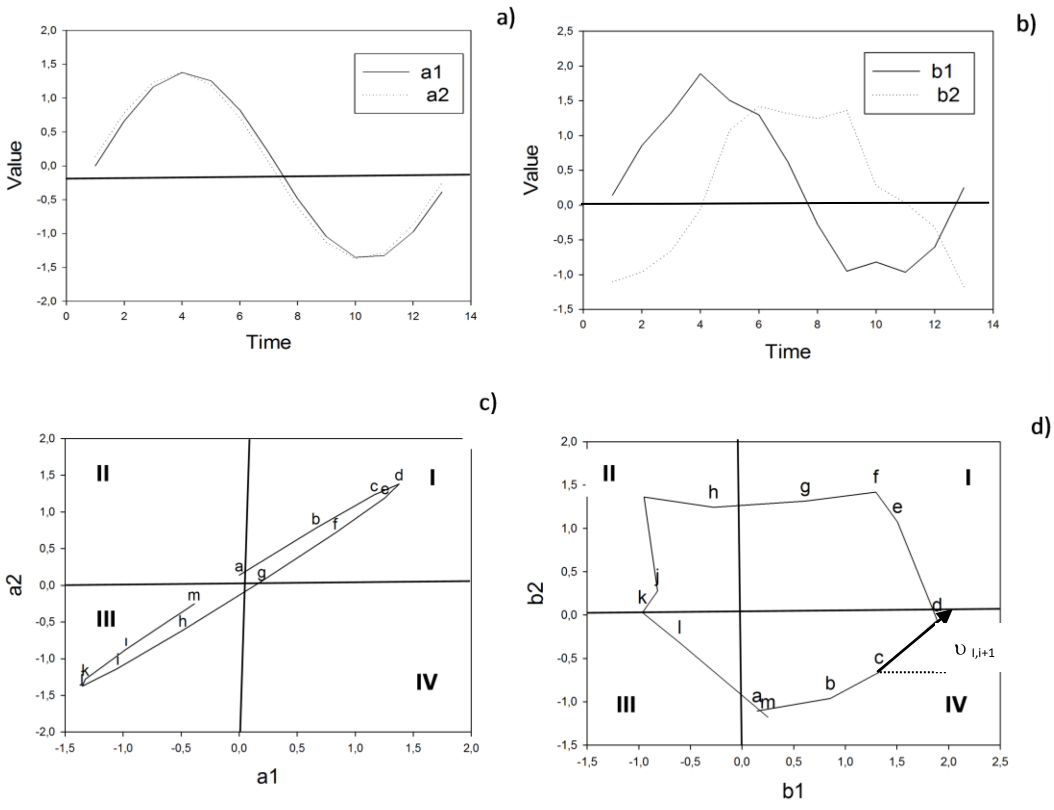


Figure 1

The relationship between two sines that are shifted relative to each other in time. Upper two panels show the time series and the lower two panels show the phase plots for the paired sines. The target sine, starting from ~zero, is depicted on the x-axis and the shifted sine is depicted on the y-axis. a) Shift τ = 0.1 and no noise; b) shift τ = 1.57 and 20% noise added. The phase plots are divided into four quadrants, I-IV. The letters and the arrows show the direction of time trajectories in the phase plots, and the angle $\upsilon_{I,i+1}$ illustrates how the phase plot patterns are described quantitatively.

However, coinciding indices may be shifted within three months, (Kholodilin and Yao 2005) so angles may deviate from the ideal values for this reason and because of noise in the data or because there is friction between variables. See Aksoy et al. (2006, Figure 1) for graphs similar to our graphs c and d, but without our interpretations.

If the two sines are shifted $\langle 0, \lambda/2 \rangle$ relative to each other in time, rotational patterns will emerge. For a lagging variable (y-axis) that has its peak after the target peak (x-axis), the trajectories will rotate counter clock-wise (d) and the directions of the trajectory will be (for sines without noise) between 90^o and 180^o if the trajectories start with high levels of both variables, and between 270^o and 360^o if the trajectories start at low values of the two variables. The Federal funds rate should be a lagging variable to output growth (Herrera and Pesavento 2009) and would rotate counter clockwise in phase plots when output growth is plotted on the x-axis. The sets of angles we obtain for each pair of variables within each period (15 ×6 period – pairs, about 9000 trajectories) can be regarded as fingerprints of the interaction between the two variables. The “fingerprints” are further described in the Method section.

We developed an algorithm for setting the Feds rate as a function of i) the current values of the Fed’s rate, inflation and unemployment, and of ii) observations of recent movements in the two latter variables. Our prescription distinguishes itself from the Taylor rule in that it is data driven and that it requires the additional assumption that successful moves by the Fed in the past can be used as prescriptions for successful moves in the future , e.g., (Rudebusch 2006; Doran and Hickey 2009; Taylor 2009). The method is easy to implement with standard computational packages.

Our main result is a nonlinear calculating rule for the Federal Funds rate. The rule is formulated as compass directions rather than slopes, and thus different from the Taylor rule (1993). However, our AFM-rule supports to a certain degree the same decisions as the Taylor rule recommend. There are, however, important differences. It does not recommend changing the Federal Funds rate if monitoring variables are already moving towards a “natural” equilibrium. We also develop an algorithm for moves that counteract stability and thus gives clues to the sensitivity of the Fed’s moves during “good” and “bad” economic periods (in terms of volatility in inflation and unemployment). The recommended changes in the Federal Funds rate should be interpreted and understood within a structural economic framework, probably more so than recommendations obtained from theoretical studies.

The rest of the paper is organized as follows: We first present the material for our study. Thereafter we give an outline of methods employed: identification of variables to be paired and their pre-treatments, the construction of phase plots, the angle frequency method, AFM, and the partial least squares method, PLS. The latter method is required for strongly covarying regressors and when there are more regressors than samples. Finally, we discuss the results relative to monetary policies and the Taylor rule.

MATERIAL

We use the following macroeconomic variables for the US economy (we use both the mathematical symbols and mnemonic identificators): three target economic time series: 1) the inflation rate (μ, Inf; in consumer prices, %); 2) industrial production (y, IP; Federal Reserve index); and 3) Unemployment (u, U; civilian unemployment rate, %). We have chosen three instrumental variables: 4) money supply m2, (M2, bill. $); 5) Federal Reserve 3-month interest rate (i, FF; effective Federal Funds rate); and 6) the interest rate spread (S; 10-year Treasury bond rate less the Federal Funds rate). All data were obtained from http://www.economagic.com/. Sims and Zha (2006) use a similar set of 6 economic time series to examine macroeconomic switching (commodity price index, M2, Federal Funds rate, GDP, consumer price index and unemployment rate). We use industrial production, IP, as a proxy for GDP, since we want all our data to be monthly.We use the term Federal funds rate about the Federal Reserve -3 month interest rate although it is normally used for overnight rates.

Data treatment.

Monthly data for all time series were sectioned into six time periods. For all periods we included data for one year prior to and one year after the period. We maintain the assumption that all variables are sufficiently stationary within the (short) six periods to calculate meaningful trajectories in phase space. Granger (1989) suggests that unit root tests are particularly important for long time series, and our series are short. See for example Clarida et al. (2000) for similar assumptions for the calculation of regression coefficients. The raw data for each period were then detrended by extracting the residuals from linear regressions of each time series against time. This corresponds to a Hodrick-Prescott filter with the relative variance of the growth component to the cyclic component set at $\lambda = \infty$. For the IP and M2 series we also used series obtained from a fitted quadratic function of time, but this did not alter our results appreciably. The inflation series is very volatile and is smoothed by calculating the 12 months running average, except at the ends where the running averages were taken over a decreasing number of months from 12 to 1. The smoothing reflects that the Fed has a horizon of one year for its inflation target, probably longer during the Greenspan period (Clarida et al. 2000; Gabriel et al. 2009).

The data for each period were then normalized to unit standard deviation. By normalizing the series, the regression slope between pairs, β, and the correlation coefficient, r, obtain the same number. It also causes slopes to have a maximum β of 1. The average value and the standard deviation over the six periods (see below) for the original series and the volatility (as the average standard deviation for the detrended series) and its standard deviation over all six periods are as follows: $\overline{Inf}$ =4.23 (2.44), $Inf_{vol.}$ = 1.3 (0.74); $\overline{IP}$=72.00 (41.80), $IP_{vol.}$=2.59 (0.62); $\bar{U}$=5.80 (1.22), $U_{vol.}$= 0.85 (0.32); $\overline{M2}$=2958 (2299), $M2_{vol.}$49.40 (29.20); $\overline{FF}$ = 6.18 (2.98), $FF_{vol.}$= 1.74 (0.68); $\bar{S}$=0.66 (0.42), $S_{vol.}$=1.27 (0.88).

US economic time periods.

We divided the US economy from 1959 to 2008 into six sub periods with similar economies based on a study by McNown and Seip (2011). Compared to the periods used by these authors, we merged their periods B (1971-73) and C (1973-78) and divide period F into two periods F and G. The periods then become, (with volatilities in Inf &U and IP following the years): A (1959:1-1971:12, vol. = 2.04, 0.32); B+C (1971:1-1979:12, vol. = 2.63,0.50); D (1979:1-1985:12, vol. = 3.42, 0.66); E (1985:1-1998:12, vol. = 1.81, 0.82); F (1998:1-2001:12, vol. = 0.64,0.52); G(2001:1-2008:12, vol. = 1.23, 0.41). Similar periods to those defined here were recently also identified by Bae et al.(2011).

The exact periodization is not critical to the present study (see comment on volatility and economic embedding below), but it is convenient that it partially corresponds to the sub periods defined by Clarida et al. (2000) that were based on the tenure of the Federal Reserve chairmen.[1] We use the term “equilibrium” for the economy when inflation, unemployment, and the Fed’s rate are at their “natural” rates (Giammarioli and Valla 2004).

METHODS

We first describe our measure for stability for the six periods in US economy. Secondly, we describe how we make “fingerprints” that characterize the interaction patterns between paired macroeconomic variables. We do this in the three steps that are used to describe the angle frequency method, AFM (Sandvik et al. 2004). Thirdly, we use partial least-squares regression analysis, PLS, to identify the interest rate policy of the Fed that supported or counteracted stability.

[1] Using periods that corresponds more closely to those of the chairmen of the Federal reserve would probably put too much emphasis on their tenure, Sims and Zha (2006).

Volatility and stability of US economy during six periods.

We calculate volatility for each of the six periods in terms of volatility in inflation, unemployment and industrial production, as the standard deviation of the data. Volatilities in inflation (smoothed) and unemployment were well correlated across periods (R = 0.949, p = 0.001), so we constructed an aggregate volatility measure consisting of the average of the two volatilities weighted equally by normalizing to unit standard deviation for both. The same correlation would not be obtained with another periodization, so it is important for combining the two volatilities, but is not required for the method. [2] This aggregate volatility function will be our loss function for this study. [3] It both serves economic welfare, Benigno and Woodford (2005), and it helps avoid transitions to unwanted states because high volatility leads to bifurcations (Scheffer et al. 2009). We thereafter constructed a stability measure by subtracting the volatility measures from the highest volatility obtained for any period.

Characterization of pair wise interactions

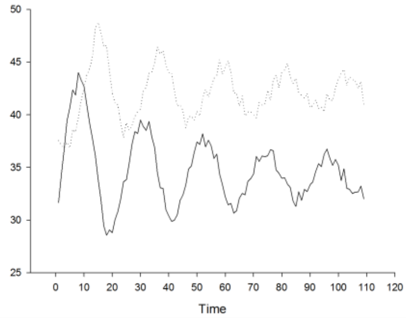
The AFM is a variant of what we could call the form factor methods. The geometric shape of time series plots are analyzed and interpreted. (One actor and time, e.g., Camacho et al. (2008) and Chauvet and Senyuz (2010); two actors and time, e.g., Seip (1997) and Sandvik et al. (2004)). The AF procedure is novel in economics, but each step is relatively conventional. Three of the four steps are depicted graphically in Figure 2.

Step 1. Choosing and pre-treating paired time series

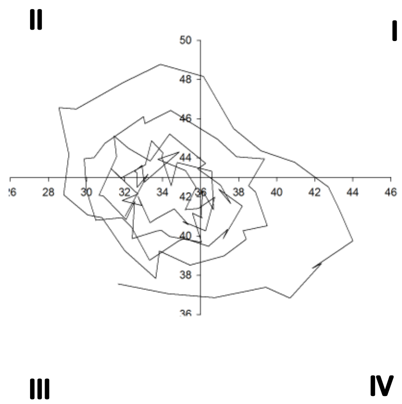
Since there are six time series, we get n = (6× 5)/2 =15 distinct pairs depicted in 15 phase plots. They are named so that variable 1 is compared to variable 2, 3,..; variable 2 to variable 3, 4,. and so on. With this rule, the x-and y-axes will change positions for some relationships relative to their normal presentations in economics. Some of the pairs are the source of established rules or principles in economics. The Taylor rule is represented by the pairs 4 (inf and FF) and 8 (IP and FF). Okun's law corresponds to pair number 6, the Phillips curve in pair 2 (Inf, U).

[2] The high correlation between volatility in inflation (smoothed) and unemployment may seem surprising. We therefore designed 6 + 2 new periods by merging the second half of one period with the first half of the next period, keeping the first and the last half of the first and last periods as separate periods. Correlating volatilities in these new series we got $r^2 = 0.02$ and p = 0.60.

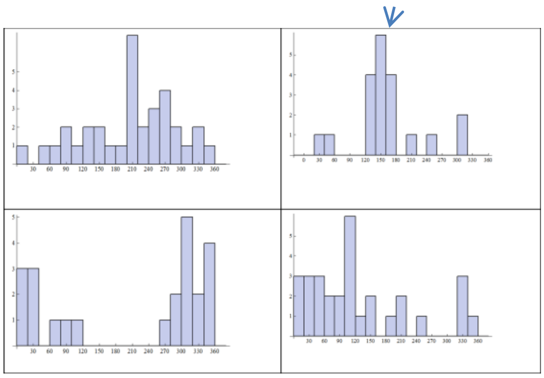
[3] Volatility is a measure of covariance, Van Zandweghe (2010). Clarida et al. (2000) compare volatility in inflation and output to obtain a loss function.



a) Time series



b) Phase plot



c) Histograms

Figure 2

The Angle frequency method. a). Time series; here it is the prototype for damped cycles with 20% multiplicative noise. The upper time series is a lagging (trailing) series for the lower, target, series. b) With the target series on the x-axis and the lagging series on the y-axis the trajectories in phase space rotate counter clock-wise. c) Within each of the quadrants of the phase plot the angles between the x-axis and the trajectories are calculated and plotted as histograms. The arrow “150 degrees” corresponds to the main directions of the trajectories in quadrant I.

Step 2. Phase plots

We plot the two series in Figure 2 a in a phase plot in Figure 2 b. The trajectories in the phase plot will rotate counter clock-wise when the lagging series (dashed) is plotted on the y-axis and the leading series (bold) is plotted on the x-axis. The number of rotations will correspond to the number of peaks in the original series, but this property will not be used here. However, it is seen that the angles in each quadrant are approximately normal to the axes of a coordinate set rotated 45 degrees counter clock-wise relative to the original axes, suggesting that rise and fall in the original series are symmetric.

Step 3. Angle histograms

We quantify the phase plot by calculating the angle between each trajectory and the x-axis by the generic formula: [4]

$$Rot = sign(\bar{v}_1 \times \bar{v}_2) \cdot A\cos\left(\frac{\bar{v}_1 \cdot \bar{v}_2}{|\bar{v}_1| \cdot |\bar{v}_2|}\right) \qquad (4)$$

Where $\bar{v}_1$ is a trajectory in the phase plot and $\bar{v}_2$ is the x-axis.

The angles, as compass degrees, retrieved from the phase plots of the paired variables are sorted into angle bins of 18^{o}. Thus for the four quadrants there are 360/18 ×4 =20 × 4 = 80 histogram columns for each phase plot. The histograms for the phase plot in Figure 2b are shown in Figure 2c. The arrow in the histogram for quadrant I points to the histogram bin for ≈ 150 degrees. The program that calculates angles and histograms was written in Mathematica from Wolfram and is available from the authors. However, the algorithm could also be programmed in Excel.

Step 4. Multivariate statistics

Angle – histograms similar to those in Figure 2 c can be treated as "fingerprints" for the interaction between paired variables. The "fingerprints" are each characterized by 80 numbers. When we want to compare time periods by the paired interactions that occur throughout the periods, the number of angles can be very large. PLS is therefore used to identify monetary policy moves by the Fed that were made during stable and volatile periods (many similar moves during a given period will give a high number in the angle bin representing that move). The regressors (X-variables) were in this study the 3 × 80 = 240

[4] Equation (4) has the following form if pasted into the C2 cell of an excel sheet and A1 to A3 (e.g., 0;1;2) and B1 to B3 (e.g., 0;0;1) contain x and y- coordinates for a paired series of three observations (in our case, one vector and the x-axis): =SIGN((A2-A1)*(B3-B2)-(B2-B1)*(A3-A2))*ACOS(((A2-A1)*(A3-A2) + (B2-B1)*(B3-B2))/(SQRT((A2-A1)^2+(B2-B1)^2)*SQRT((A3-A2)^2+(B3-B2)^2))). The result is 0,785398, that is 45 degrees. The actual algorithm is a little different, but gives identical results.

angle bins for these phase plots that included the policy instrument variable, FF, and the three candidate guiding variables, Inf, U and IP, that is, Inf-FF, IP-FF and U-FF. We used measures of stability as dependent variable (Y- variable). Since we have six periods, the PLS have a (6 ×1) matrix as Y-variable and a (6 × 240) matrix as X- variable.

To analyze such data sets, in particular sets with more columns than rows, partial least squares, PLS, techniques are required (Wold et al. 1987; Martens and Næs 1989). It is used, for example, for spectroscopy data in chemistry, where the regressors may be peaks among 100s of peak positions, and the independent variables are chemical components, e.g., Vigneau et al.(1996). The PLS model was obtained by a straight forward application of the algorithm, using cross validation and employing the program Unscrambler © from CAMO (Trondheim, Norway). Programs like Matlab have the same functionalities. The frequency data were normalized so that the length of the original time series did not affect the results, except that shorter time series may be noisier.

The PLS produces two plots with principal components, PC_1, PC_2, along the axes (or other combinations of PCs). The score plot shows how the periods are related in a least-squares distance sense. The loading plot shows how angles in each quadrant contribute to the explanation of the Y-variable. The angles that explain high stability are within the 95% confidence interval of the position of the Y-variable in the PLS - loading plot. The positions of angles counteracting stability were furthest from stability point along a line through origin. The latter were also identified in our study using volatility as independent Y- variable.

Uncertainty. To find the uncertainty in our PLS algorithm we used Monte Carlo simulations. We constructed phase plots for eight pairs consisting of random numbers and added these to the series for the 15 paired economic variables. We represented the random series with 140 samples to obtain lengths comparable with the observed data that consist of monthly samples for 4 to 14 years. The distribution of the eight pairs of random numbers were used to estimate the standard deviation and the standard error for sample positions. Since the pairs contaminated the original data set, the error statistics give only guiding numbers. However, confidence intervals were calculated at the 5% level (instead of a 10% level).

Comparing results based on normalized data to theoretical relationships. For the two relationships, Eqs. 1 and 2, we have quoted representative numbers for the coefficients. To compare these coefficients with the angles obtained with our method there are two issues that have to be addressed:

i) *β- coefficients versus compass degrees*. The β - coefficients show the slopes, that is, they give the response in the Federal funds rate ΔFF when e.g., inflation, π, decreases or increases and the response is similar below or above the mean values of π. However, the compass angles $v_{i,i+1}$ are functions of the variables mean values and their direction : v = f($\bar{\iota}$, $\bar{\pi}$, sign Δi, signΔπ).

ii) Since the time series have to be normalized to unit standard deviation when we calculated angles, we use the standard deviation of the data within each period as adjustment factors. The β -coefficient is calculated for data within each period and then averaged. However, it may differ from the β - coefficient for the full data set. See Russell and Banerjee (2008 Fig 9) for a an example where the period coefficients are negative, but the coefficient for the full set is positive. The method is comparable to the Theil rank- invariant linear regression analysis, but we use only the observed subset of trajectories in phase space (Theil 1950; Seip and Goldstein 1994).

RESULTS

We first present results for the relationship between volatility during six periods in US economic history and the Fed's interest rate response to changes in 3 variables: inflation, unemployment and industrial production during these six periods. The mean value will be compared to the variables' "natural" rates in the economy.

The Fed's moves during low and high stability

The characteristic angles for moves that support or counteract stability are retrieved from the loading plots of the PLS and are shown in Tables 1 and 2. The PC_1 of the plot explains 24 % of the variance in the stability and PC_2 explains 19% of the variance. (plots not shown). The characteristics are given in terms of guiding variable (FF versus inf, U, or IP respectively), quadrants (I-IV) and angles (0-360^o).

Table 1 Moves in the Fed's rate that support stability

The Fed's rate in response to changes in inflation, $FF = \beta_\pi \times \pi$; unemployment, $FF = \beta_U \times U$; and industrial production, $FF = \beta_y \times y$. Roman numbers, I - IV, designate quadrants, so that quadrant I has FF and target variables with both values above average. The quadrants are numbered counter clockwise. *ws* = weakly significant. The results for industrial production, y , were not significant. In quadrants with no positive recommendation, the advice is "do nothing". See graphs in Figure 3

Inflation, π		Unemployment, U		Industrial production, y	
Quadrant (I-IV) and angle, v_π (0-360 degrees)	Slope $\beta_\pi = \tan(v_\pi)$	Quadrant (I-IV) and angle, v_U (0-360 degrees)	Slope $\beta_U = \tan(v_{U)})$	Quadrant (I-IV) and angle, v_{IP} (0-360 degrees)	Slope, $\beta_y = \tan(v_y)$
I-27 $\pi > \bar{\pi}$, $FF > \overline{FF}$	0.51 $\Delta\pi > 0$	IV-9 $U > \bar{U}$, $FF < \overline{FF}$	0.16 $\Delta U > 0$	I-225 $y > \bar{y}$, $FF > \overline{FF}$	1.0 $\Delta y < 0$
II-243 $\Pi < \bar{\pi}$, $FF > \overline{FF}$	1.96 $\Delta\pi < 0$	IV-297	-1.96 $\Delta U > 0$		
		II-333 $U > \bar{U}$, $FF < \overline{FF}$ *II-153(ws)*	-0.51 $\Delta U > 0$; $\Delta U < 0$		

Table 2 Moves in the Fed's rate that counteract stability

Legends as in Table 1

Inflation, π		Unemployment, U		Industrial production, y	
Quadrant (I-IV) and angle, v_π (0-360 degrees)	Slope $\beta_\pi = \tan(v_\pi)$	Quadrant (I-IV) and angle, v_U (0-360 degrees)	Slope $\beta_U = \tan(v_{U)})$	Quadrant (I-IV) and angle, v_y (0-360 degrees)	Slope, $\beta_y = \tan(v_y)$
I-261 $\pi > \bar{\pi}$, $FF > \overline{FF}$	6.31 Δπ < 0	III-99 $U < \bar{U}$, $FF < \overline{FF}$	-6.3 ΔU<0	I-81 $y > \bar{y}$, $FF > \overline{FF}$	6.31 Δy> 0
III-9 $\Pi < \bar{\pi}$, $FF < \overline{FF}$	0.16 Δπ > 0	III-117	-1.96 ΔU<0	I-261	-6.31 Δy< 0
III-27	0.51 Δπ > 0	II-135 $U < \bar{U}$, $FF > \overline{FF}$	-1 ΔU <0	IV-81 $y > \bar{y}$, $FF < \overline{FF}$	6.31 Δy> 0
		IV-99 $U > \bar{U}$, $FF < \overline{FF}$	-6.31 ΔU <0	IV-27	0.51 Δy> 0

Figure 3 B and C shows the result for the Fed's rate versus inflation and unemployment as arrows in their respective phase plots. Note that the arrows are important, it is only movements in the direction of the arrows that will give ΔFF ≠ 0. The two dashed arrows a and b will be explained below. The results for IP were not significant and are not shown. Numbers at midpoint of axes are the average of the averages of variable values over the six periods A-G and their standard deviation. The graphs are similar to the policy response graphs in Aksoy et al. (2006 , Figure 1), but our responses are here represented by arrows rather than bi-directional lines. The results will be formulated as follows; first we identify the current states of FF and the guiding variables. Then we describe the stability supporting moves for FF depending on moves in the guiding variable. Lastly, we describe moves that would have counteracted stability. The arrows show the direction of the movements. The upper two panels, A, in Fig 3 show a schematic version of the Taylor rule.

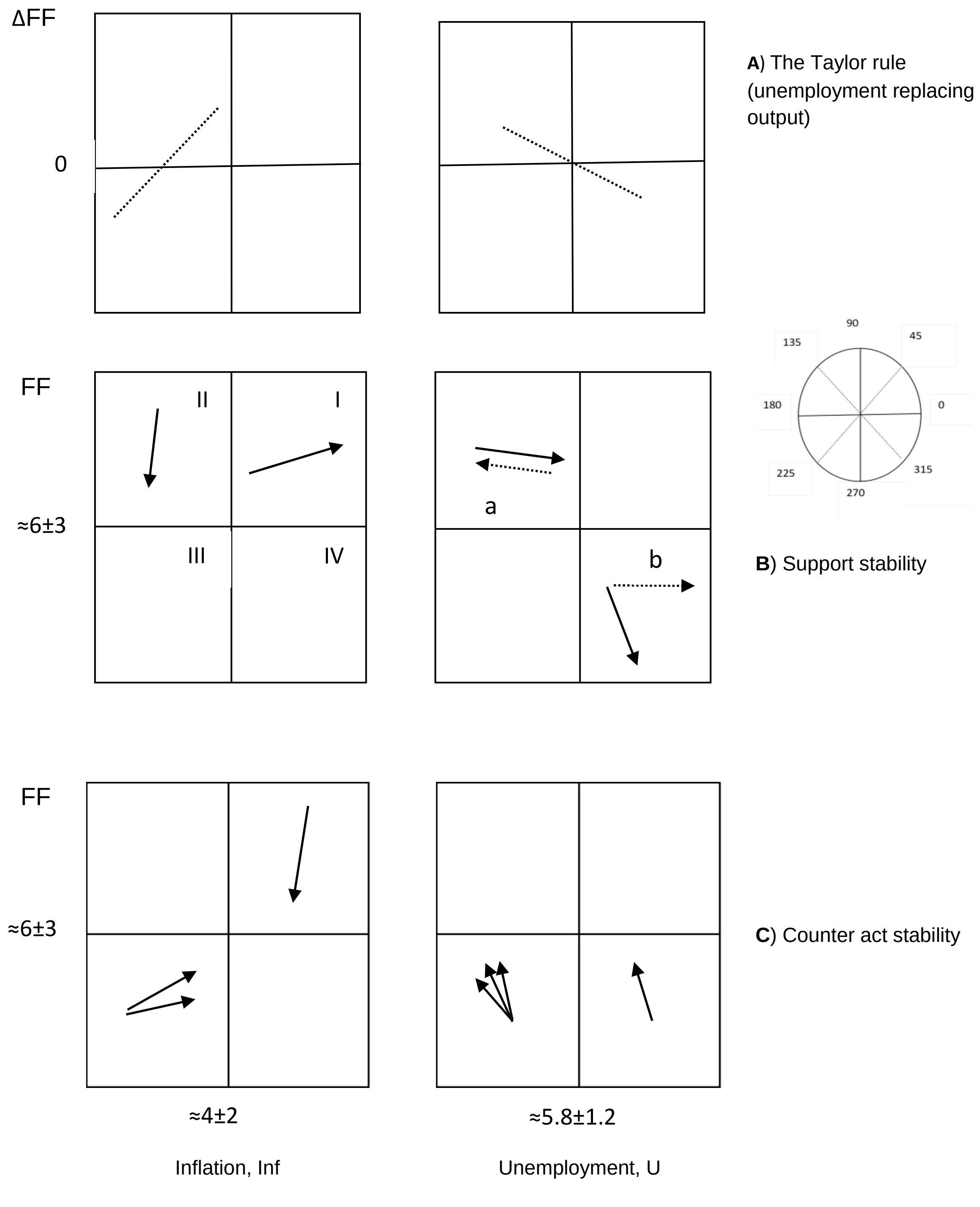


Figure 3. Supporting and counteracting changes in the Fed's rate, FF, in response to changes in inflation (left) and unemployment (right). Federal funds rate, inflation and unemployment are all normalized to unit standard deviation. Numbers at midpoints of the axes are averages of non-normalized values. The inset shows a compass rose. The arrows were draw from information in Tables 1 and 2. **A**): schematic representation of the Taylor rule, but with unemployment replacing output as independent variable (see text). **B**): Responses that support stability. The arrows show the Feds response to changes in inflation and unemployment that most clearly distinguish the six periods

in US economic history. The dashed arrow “a” is only weakly significant. The dashed arrow “b” may correspond to situations where FF ≈ 0. **C**) Responses that counter act stability.

Inflation as target. Panel B, left square, shows moves that increase stability. We found that at a high value of FF and at lower than average inflation, stability supporting FF moves were a sharp decrease in FF with slowly decreasing inflation (quadrant II). However, from a high value of both FF and inflation, a slow increase in FF with rapidly increasing inflation supported stability.

Panel C, lower left square shows moves that decreased stability. At low values of both FF and inflation, stability decreased if FF is increased with increasing inflation. At high values of both FF and inflation, stability decreased if FF was decreased sharply with a slowly decreasing inflation (quadrant I).

Unemployment as target. Panel B, upper left square shows moves that increased stability (quadrant II). We found that at high levels of FF and low levels of unemployment slowly decreasing the Feds rate with increasing unemployment supported stability. However, the dashed arrow (a) - which is only weakly significant - shows that at low unemployment, increasing the Fed’s rate with decreasing unemployment, may also contribute to increasing stability. At low levels of FF and high level of unemployment, rapidly decreasing FF with slowly increasing unemployment supports stability.

The second dashed arrow (b) will be discussed below. Panel C, lower right square, shows moves that decrease stability. At low levels of FF, but at low as well as high level of unemployment, increasing FF sharply with decreasing unemployment decreased stability. The destabilizing effects appeared to be particularly strong at low values of both FF and unemployment.

Comparison with the Taylor rule. We have indicated a comparison with the Taylor rule in the upper panel of Figure 3 by recalculating the Taylor slope, 1.5 for inflation, to its standardized units, 1.1, and positioning it approximately at an inflation rate of 2%. Our prescription is overall consistent with the Taylor rule, but recommends a more rapid decrease at low inflation rates and a slower increase at higher inflation rates. The turning point for inflation is higher in our model than for the Taylor rule (4% versus 2%). The Taylor rule is linear and gives the same slopes for the Fed’s response above and below the guiding variables “natural” rates, and it describes a response irrespectively of how the economy moves at the time of the decision if the economy is not at equilibrium.

Applications to the period 2000-2008

In this section we compare the Fed's actual fund rate, our AFM policy rule, and the Taylor rule for the period 2000 to 2008. We find that the AFM policy rule is fairly consistent with the Fed's policy during this period, prescribing a lowering of the Fed's rate when the rate was actual lowered, Fig 4, but only prescribed an increase in the rate for a short period (2007). Our rule contrasts with the Taylor rule in that it (with one exception) does not give prescriptions when the economy is moving towards equilibrium.

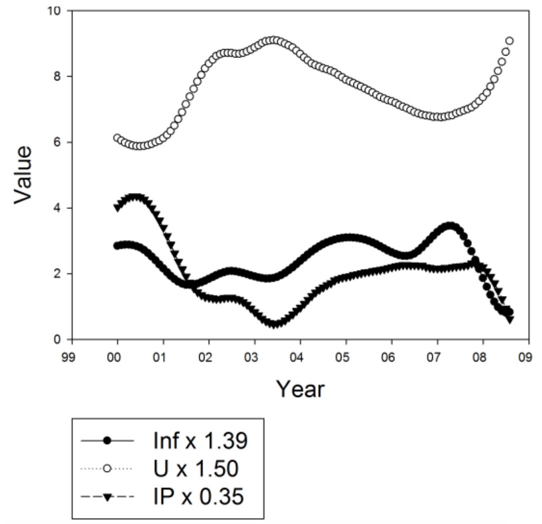
Backgound. The period 2000-2008 corresponds to our last period, G. It is the period with the next lowest volatility out of our six periods. Thus, we would expect that our AFM- rule would reflect fairly well the Fed's interest rate movements during this period. We chose this period because it is discussed by Rudebusch (2009), Fernandez et al. (2010), Catte et al.(2011) and others. For the sub period 2003 to 2007, Taylor (1993) asserted that the Federal funds rate should have been higher than the rates the Fed actually set.

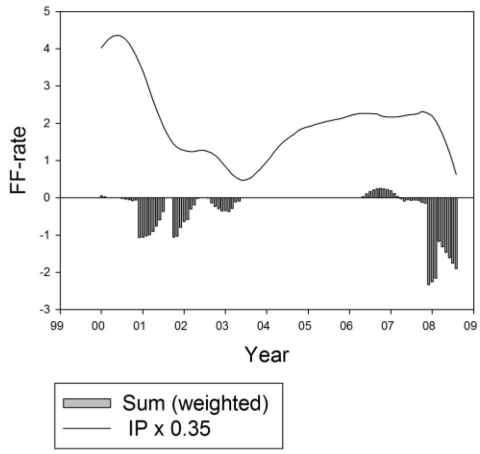
Conducting the test. In the test we chose to smooth the inflation time series by calculating annual data and then interpolate to obtain monthly data.[5] It will then be easier to see how our ΔFF values are calculated.

At the end of each month we calculate the movements in inflation, ΔInf, and unemployment, ΔU, (based on the smoothed series). We then identify if the Federal fund's rate, inflation, and unemployment are below or above their averages (as in Figure 3). Depending upon their current values we calculate the response values $\Delta FF_{\pi} = \tan(\upsilon_{FF,\pi}) \times \Delta\pi$ and $\Delta FF_U = \tan(\upsilon_{FF,U}) \times \Delta U$ with the angles from Table 1. Note that ΔFF is only given a non-zero value if the movements are in the direction shown by the arrows in Fig 3. All calculations were made in Excel. The results are shown graphically for unemployment (Fig 4 c) and inflation (Fig 4 d) and with a weighted sum (Fig 4b). In the latter case we let the two components weight equally by multiplying each with the standard deviations of the series of moves 2000-08. To compare with the Taylor rule, we also relaxed the restriction on the direction of the recent movements in inflation and unemployment, that is, there is no reference to whether the economy is moving away from equilibrium or towards it. The results are shown in Figures 4 e and f.

[5] We use a negative exponential smoothing algorithm using a second order polynomial fitting (Sigma Plot©)

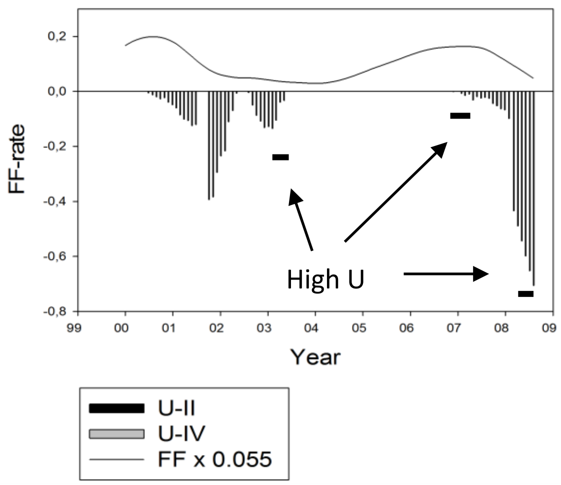
AFM-rule, compass directions, b) responses to inflation and unemployment combined

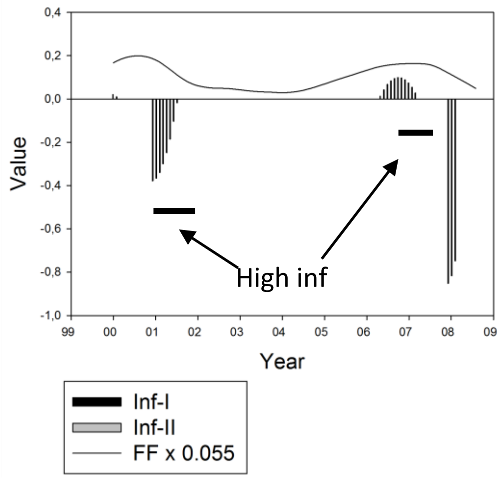




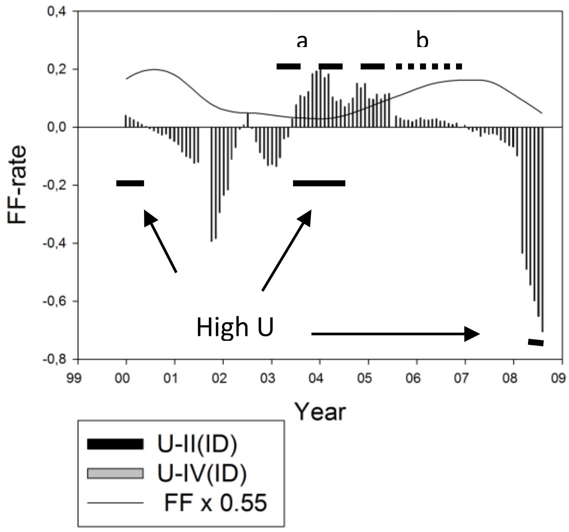
c) d)

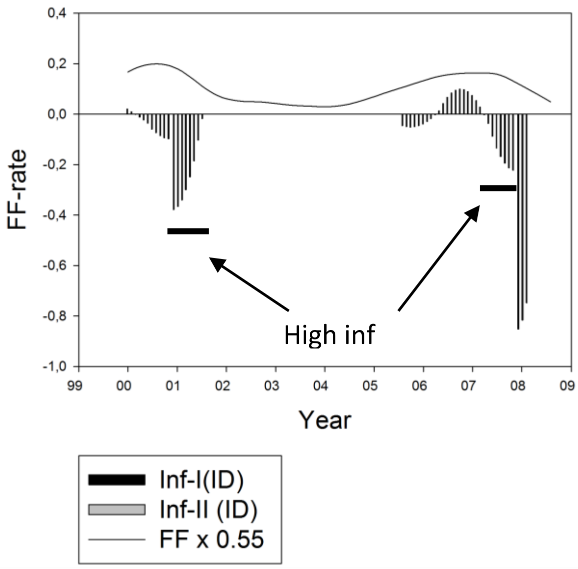
AFM-rule; compass directions





AFM-rule relaxed, coefficients e) f)





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data are smoothed and normalized to unit standard deviation.) b) Recommended monthly changes in the Fed's interest rate given (bars): i) the values of (smoothed) inflation, unemployment and Fed' rate and ii) recent movements in inflation (smoothed) and unemployment. c) The component due to low unemployment at high federal funds rate (U-II) and due to high unemployment at low federal funds rate (U-IV). d) The components due to inflation (low- Inf-II, high –Inf -I) at high federal funds rate. e) and f) The rule, but relaxed with respect to direction of movements in unemployment and inflation. Lines a and b are explained in text. The arrows point to movements at high unemployment and high inflation.

Our AFM-rule basically describe what the Fed actually did during the 2000-08 period, Fig 4 c) and d). The largest contribution for changes came from observations of unemployment, but both variables tend to give the same recommendation. There is one exception; in 2007 there is a prescription to increase the FF-rate based on the observations of the inflation rate. The figure also shows contributions that came from low and high values of the two variables. When we relaxed the restriction on directions, the unemployment component of the rule recommends an increase in the Feds rate from mid 2003 to 2007, Fig 4 e). However, except for the small rise from mid 2006 to 2007, there was no support for this rise in the learning sets of the AFM-rule (six periods during 1959 to 2008).

DISCUSSION

We first discuss the ability of the angle frequency method, AFM, to design rules for modifying the Fed's policy. Then we discuss the application of the rules to the period 2000 to 2008 and compare the results of the AFM-rule to the Fed's actual policy, to the prescriptions of the Taylor rule and to nonlinear modifications of that rule.

The Feds response to variables at high and low levels of macroeconomic variables. We found that inflation and unemployment was the best guiding variables for setting the Feds rate. Industrial production, IP, as in the Taylor rule, gave no significant signatures. Interestingly, Clarida et al. (2000) use both GDP and unemployment to measure output gap (with the sign of the last series switched). Givens (2009) found the price of labor or the nominal wage as a better guiding variable than output. Hayat and Mishra (2010) found that output gap did not have a significant importance for the Fed's policy. As with us, Fernandez et al. (2010) found that unemployment was a better guiding variable than GDP (or industrial production).

The comparison with the Taylor rule in the upper panel of Figure 3 assumes that the natural unemployment rate, or the NAIRU, is about 5-6% and that the coefficient in Okun's law ≈ 2 compensates the difference in standard deviation for U and FF data (0.85 / 1.74). Our AFM-rule recommends changes in the Fed's rate much like the Taylor rule, but strengthens the recommendation to decrease the Fed's rate at high unemployment (quadrant IV; or large negative output gap), as well as strengthening the recommendation to decrease the Fed's rate from a high value once inflation is decreasing. Thus, the AFM rule is nonlinear, supporting findings by Hayat and Mishra (2010), Dolado et al.(2004) and Kim et al.(2005). However, our rules have the extra characteristic that they are not indifferent to the direction of recent changes in inflation and unemployment.

Our results can be compared to those of Aksoy et al.(2006), Taylor and Davradakis (2006) and Hayat and Mishra (2010). All three studies recognize a band around, or below, a target value of monitoring variables that should not solicit any reaction from the Federal reserve. Taylor and Davradakis (2006) show that in the UK economy the FF rate and the interest rate make "random" walks when values are within a band defined as less than 0.5 % below the target. Aksoy et al. (2006) maintain that an opportunistic approach with no reaction by the Federal reserve for small changes in inflation (their Figure 1) will achieve disinflation at lower output costs than a linear strategy. If movements in the FF-rate or Inf are random or include random shocks that are within a band around target values, the results above would in our model correspond to the requirement for a significant movement in the variables before the Federal Reserve respond. However, our results is a little different, a response is recommended for low values of Inf, but only if the FF-rate is above average.

What not to do. In contrast to most other studies, we also identify what the Fed should not do, but has done. Our results show for example that maintaining low, or slowly increasing the Fed's rate while the inflation is rapidly increasing, would decrease stability (β_{Inf} = 0.16 to 0.51; lower left quadrant). Clarida et al. (2000) showed that the Fed during the volatile pre-1979 period maintained persistently low short- term rates, $\beta_{Inf} \approx 0.86 < 1.0$. A second destabilizing effect is to decrease the rate sharply when inflation starts to decrease from a high value. A third move that destabilizes the economy is to increase the rate rapidly ($\beta_U \approx$-1 to -6) while unemployment is decreasing from both a high and a low value. The latter prescription says that, although the Fed should decrease its rate if unemployment increases from a high value, it should not immediately reverse this policy if unemployment decreases. The strange result for the situation with low Federal fund's rate and high unemployment, namely that the rate should be kept constant while unemployment is increasing (arrow b), may reflect this policy and thus be an artifact that reflects that the Fed's rate cannot be below zero. In such situations, other rate policies or other monetary instrument may have to be used, (Eggertsson and Woodford 2003; McGough et al. 2005; Doh 2010).

Our results suggest that that the most important stabilizing policies were carried out during higher than average values of the economic variables (3 of 4 in Fig 3 B), whereas destabilizing policies were policies that were carried out wrongly at low values of the variables (3 of 4 in Fig 3 C). It is interesting that many of the destabilizing policies were those that increased the Fed's rate, that is, applied the "brakes" inappropriately. Although our results are based on monthly values and moves, the rule could be adopted for any suitable time window.

Comparing actual Fed's rates and models for the period 2000-2008

There is evidence that the Taylor rule recommendation that the Fed should have increased its rate from 2003 to 2007 was right (Rudebusch 2009). However, Fernandez et al. (2010) suggest that this conclusion depends upon the smoothing rule used for the output gap. With the AFM-rule there is no such prescription, but a weak recommendation to increase the rate slightly from 2006 to 2007. During the development of the method, several choices have to be made. We will here address four of these that are of particular concern.

Embedding and shocks. The actual policies also include responses to shocks that may not reappear in the future. Shocks are believed to last for relatively short periods, e.g. 1-2 years (Herrera and Pesavento 2009), and to have limited sizes (Taylor and Davradakis 2006). Our periods are longer, 4-14 years. Small shocks may thus not be very important in the present context.

Smoothing the variables. In our model we used two smoothing procedures for inflation, one during model development and a second for applying the rules that give fairly similar results, but the latter is easier to compare to the inflation rate's normal representation, e.g., Dornbusch et al.(2008).

Equilibrium. It is interesting that triggering values for changing the Fed' rate occurs both at high and low unemployment values, whereas triggering values occurs mainly at low inflation rates, Fig 4. Taylor and Davradakis (2006) and Aksoy et al. (2006) both suggest an inflation rate of 3.1 % as the lower limit for when the Fed should act.

Adding contributions. Adding contributions from inflation and unemployment may not the most correct way to combine the two contributions. (The two series are weekly negatively correlated β – coefficient = - 0.47; R^2 = 0, 22). Trecroci and Vassalli (2010) suggest that emphasis was on response to inflation in the 1980s, whereas the 1990s and 2000s saw a growing emphasis on responses to output. We do not yet know how to combine the two contributions. Applying the AFM to a 3D representation of the economy (FF, π and U simultaneously) could be one solution.

In spite of all alternatives we do not think our main result would change with other reasonable choices, and we find support for this in that our recommendations largely are in agreement with the findings in other studies cited above.

Acknowledgements

We would like to acknowledge the help of Nina Holmengen, Ørnulf Staff, Tore Møller Jonassen with program development and Janet W. Campbell for valuable advices. We also were helped by Rolf Ingebrigtsen who discussed control theory with us.

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