Federal Reserve Policy viewed through a Money Supply Lens

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Abstract

This paper examines postwar U.S. Federal Reserve supply of high powered money and its macroeconomic implications. We provide evidence that the growth rate of nonborrowed reserves has responded to expected inflation and to the output-gap. While the feedback from output-gap is always significantly negative, the feedback from expected inflation varies substantially. For the post-1979 period we find a significant and negative feedback indicating an anti-inflationary stance during the Volcker-Greenspan era. For the pre-Volcker era we find a significantly positive feedback, indicating that monetary policy has been accommodating in the pre-1979 period. These results, which are unchanged when we use real time data instead of revised data, support the common view that Federal Reserve policy has been less stabilizing in the 1970's. However, our theoretical analysis indicates that Federal Reserve policy has never allowed for endogenous fluctuations, which contrasts conclusions drawn from the analysis of the federal funds rate behavior.

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1 Introduction

This paper examines postwar U.S. Federal Reserve money supply behavior. The main aim of the analysis is to disclose whether the well-established shift in the conduct of monetary policy between the pre-1979 and the post-1979 period is mirrored in systematic adjustments of high powered money. The approach in the paper corresponds to the one of Clarida et al. (2000) who estimate forward-looking feedback rules for the federal funds rate and assess their stability implications in a New Keynesian model. In contrast to their analysis we look at the behavior of the underlying money supply and estimate forward-looking reaction functions for the growth rate of (nonborrowed) reserves. Since the latter serves as the monetary instrument that implements particular interest rate targets (see Meulendyke, 1998), one might expect that systematic changes of nonborrowed reserved and the federal funds rate are closely related. In accordance with this view we find substantial differences in the way the Federal Reserve has adjusted money supply in response to changes in macroeconomic indicators between the pre-1979 and the post-1979 period. In this regard our results confirm conclusions drawn from federal funds rate analyses. However, the theoretical part of the paper indicates that the alleged macroeconomic instability in the pre-1979 period relies on the reduction of monetary policy to state contingent interest rate adjustments.

The starting point of our analysis is that the supply of nonborrowed reserves rather than the federal funds rate is controlled by Federal Reserve. We share this view for example with Eichenbaum (1992) or Strongin (1995) who analyzed the effects of monetary policy shocks measured by unanticipated changes in nonborrowed reserves in vector autoregressions (VARs). The identification of money supply shocks is based on the isolation of exogenous policy actions from systematic money supply adjustments.[2] However, the implied reaction function for the supply of nonborrowed reserves has drawn much less attention than reaction functions for the federal funds rate. Taking a closer look at the latter, several studies applying single equation estimations have shown that federal funds rate movements can be summarized by forward-looking reaction functions (see Woodford, 2003, for an overview). These reaction functions, which are often called "Taylor-rules", mainly show that the federal funds rate has been adjusted in response to changes in expected inflation, in the output-gap, and in its own lag. Furthermore, shifts in the reactiveness of the federal funds rate have been taken as an indicator for shifts in the conduct of monetary policy. In their seminal paper, Clarida et al. (2000) have shown that the feedback from expected inflation to the federal funds rate has been less pronounced in the pre-1979 (pre-Volcker) period than in the period after 1979 (Volcker-Greenspan), the year Paul Volcker's mandate started as Chairman of the Board of Governors of the Federal

[2] Bernanke and Mihov (1998) and Christiano et al. (1999) also apply VARs to examine responses to monetary policy shocks which are identified with nonborrowed reserve innovations.

Reserve System.

Corresponding to Clarida et al.'s (2000) analysis, we estimate a forward-looking reaction function for the growth rate of nonborrowed reserves for U.S. postwar (quarterly) data. We provide evidence that the growth rate of nonborrowed reserves has significantly responded to changes in the expected inflation rate, in the output-gap, and in its own lag. In particular, we find that the growth rate of nonborrowed reserves has always responded significantly negative to a rise in the output-gap. In contrast, money supply responses to changes in expected inflation exhibit a substantial difference between the pre-1979 and the post-1979 period. The inflation feedback is significantly negative during the Volcker-Greenspan era. On the contrary, the inflation feedback in the pre-Volcker era is found to be significantly positive. Given that common wisdom would suggest a stabilizing money supply regime to exhibit a negative feedback from expected inflation and the output-gap, these results indicate that Federal Reserve policy in the Volcker-Greenspan has aimed to stabilize inflation whereas money supply in the pre-Volcker period has been accommodating. Our estimates thus confirm the view that Federal Reserve policy "was less well managed" in the pre-Volcker period (see Clarida et al. 2000). This qualitative shift in the money supply behavior is further found to be robust for various specifications of the forward-looking (inflation) component and for the output-gap.

To further assess the robustness of our results, we account for an important argument recently raised by many authors that monetary policy assessments based on ex-post data might lead to biased results. Specifically, estimations conducted by Orphanides (2001, 2002) for forward-looking reaction functions for the federal funds rate with real-time data indicate that interest rate adjustments hardly differed between the pre-1979 period and the post-1979 period. Following Orphanides (2002) we therefore estimate money supply reaction functions using the so-called Greenbook data which were available for the Federal Reserve in real time. In contrast to Orphanides (2002), we thereby do not find substantial differences to the estimates for ex-post data. Thus, the estimates of money supply reaction functions seem to be less sensitive to the way inflation expectations are modelled and provide support for Clarida et al.' (2000) results.

In the second part of the paper we conduct an exercise which corresponds to the theoretical analysis in Clarida et al. (2000). We apply a standard sticky price model where monetary policy is summarized by a state contingent money supply rather than by an interest rate rule. This model, which is otherwise identical with the standard New Keynesian model, is sufficiently simple to derive conditions for equilibrium stability and uniqueness in an analytical way. As the main principle it is shown that the money growth rate should not rise with (expected) inflation by more than one for one in order to avoid instability and equilibrium multiplicity. Thus, the money growth policy should satisfy a restriction on the inflation feedback which relates to the well-known "Taylor-principle" (see Woodford, 2001).[3] We then check the stability and determinacy implications of money supply reaction functions with feedback coefficients taken from our estimations for both sample periods. We thereby find that all money supply reaction functions are associated with equilibrium stability and uniqueness for any reasonable set of parameter values. Thus, we cannot confirm Clarida et al.'s (2000) results that Federal Reserve policy in the pre-1979 period failed to pin down an unique rational expectations equilibrium. Put differently, our theoretical analysis indicates that Federal Reserve policy has never allowed for endogenous fluctuations.

To summarize, viewing Federal Reserve policy through a money supply lens shows that there has been a substantial shift in the conduct of monetary policy, regardless whether the assessment is based on ex-post data or real time data. While this results confirms the view that pre-Volcker Federal Reserve policy has been less stabilizing, our theoretical result indicates that monetary policy before and after 1979 mainly differed in the ability to stabilize fluctuations caused by fundamental rather than by non-fundamental shocks.

The remainder of the paper is set out as follows. Section 2 provides the empirical analysis. Section 4 provides an efficiency analysis of money supply in a standard sticky price model and examines the model's local dynamics under forward-looking money supply reaction functions. Section 5 concludes.

2 Postwar Federal Reserve money supply

It has become common practice in theoretical and empirical analysis to characterize monetary policy by feedback rules for a short-run interest rate, which serves as the central bank's operating target. Empirical studies by Taylor (1999), Clarida et al. (2000) or Orphanides (2001) have shown that the systematic component of postwar U.S. monetary policy can reasonably be described by state contingent adjustments of the federal funds rate. However, in order to control the interest rate, the Federal Reserve adjusts quantities in open market operations. Put differently, sales and purchases of nonborrowed reserves in open market operations actually serve as monetary instruments, which are used to implement particular interest rate targets (see Meulendyke, 1998).[4]

In this Section, we examine whether U.S. monetary policy can alternatively be charac-

[3] According to the Taylor-principle equilibrium stability and uniqueness is ensured when the real interest rate increases with (expected) inflation. Correspondingly, the growth rate of real balances should decrease with (expected) inflation (see Schabert, 2005).

[4] By purchasing or selling securities through open market operations the Federal Reserve adjusts the supply of nonborrowed reserves. In addition, the Federal Reserve can supply reserves to the banking system by lending through the Federal Reserve discount window. Reserves obtained through this channel are known as borrowed reserves. In general, banks are expected to make use of the discount window borrowing only after drawing on all other available sources of funds. With the development of financial markets it has become more feasible and efficient to provide reserves primarily through open market operations. Accordingly, discount window lending has accounted for a relatively small part of total reserves (see Meulendyke, 1998).

terized by systematic adjustments of the monetary instrument, i.e., nonborrowed reserves. Corresponding to the studies on interest rate feedback rules, we thereby aim to unveil how the monetary policy stance systematically changes with (expected) changes in core macroeconomic variables, i.e., inflation and the output-gap. Further, we want to examine if there exists a shift in the Federal Reserve's money supply that relates to the well-established shift in the federal funds rate behavior, which has been interpreted as an indication that Federal Reserve policy in pre-1979 (pre-Volcker) period has been less stabilizing than in the post-1979 (Volcker-Greenspan) period (see Clarida et al., 2000).

2.1 Adjustments of nonborrowed reserves

The behavior of nonborrowed reserves and the federal funds rate has been examined in a number of studies applying high and low frequency data. Studies by Hamilton (1997), Thornton (2001), and Carpenter and Demiralp (2005) build on comprehensive specifications of the market for federal reserves, focussing on the behavior of the federal funds rate and money supply on the basis of high frequency data (daily and monthly frequency). One central question in this literature is the existence of a *liquidity effect*, i.e., a negative relation between the supply of reserves and the change in the federal funds rate. While the existence of such a relationship seems to be necessary for the control of the federal funds rate, there is no clear evidence in favor of a liquidity effect (see Leeper and Gordon, 1992, or Thornton, 2001).

Unlike these studies, our analysis of monetary policy draws on data at business cycle frequencies. Thus, distortions arising through non-monetary policy effects at higher frequencies are mostly neutralized in our analysis using quarterly data. Even though the Federal Reserve attempts to sterilize unanticipated money market distortions, it cannot fully neutralize their effects on a daily basis. Hence, the behavior of reserves at higher frequency can be distorted by a mismatch between the Federal Reserve's forecast of the supply of reserves and the actual supply of reserves perceived in the banking system. Conversely, changes in the supply of nonborrowed reserves at lower frequency are primarily due to changes in the monetary policy stance.

Another branch of the literature, which is more related to the purpose of this paper, has focussed on the monetary transmission mechanism at lower frequency, where monetary policy shocks are identified by changes in nonborrowed reserves. Structural vector autoregressions (SVARs) in Eichenbaum (1992), Strongin (1995), and Christiano et al. (1999) show that unanticipated changes in the supply of nonborrowed reserves yield changes in real activity and aggregate prices. Nonborrowed reserves innovations further lead to significant liquidity effects. In order to identify monetary policy shocks, exogenous policy changes have to be isolated from endogenous reactions of the monetary policy stance. Hence, the SVARs contain a reaction function for nonborrowed reserves, which describe how the Federal Reserve has adjusted money supply contingent on changes in macroeconomic variables of interest.

To obtain a first impression about the way nonborrowed reserves vary systematically with changes in main macroeconomic indicators, we estimate a reduced-form VAR using quarterly data for the U.S. Our particular focus is on the differences in the reaction function for nonborrowed reserves between different sample periods. Our estimated VAR corresponds to the benchmark specification of Christiano et al. (1999) and includes the log of real GDP (Y), the log of the implicit GDP deflator (P), the change in an index of commodity prices (CP), the federal funds rate (FF), the log of total reserves (TR) and the log of nonborrowed reserves plus extended credit (NBR), respectively. The VAR is estimated for different time horizons using two lags. The first time horizon matches the overall sample period and runs from 1960 Q1 to 1999 Q4.

We also estimate the VAR for two subsamples, namely, for the periods before and after 1979, the year Paul Volcker's mandate started as Chairman of the Board of Governors of the Federal Reserve System. The first subsample covers the period 1960 Q1 to 1979 Q2 (pre-Volcker period), and the second subsample spans the period 1982 Q4 to 1999 Q4 (Volcker-Greenspan period). It is now widely agreed that Federal Reserve policy has been less well managed in the pre-Volcker period than in the Volcker-Greenspan period. According to this view, Federal Reserve policy during the pre-Volcker period has been less anti-inflationary than after Paul Volcker's appointment as Fed Chairman (see Friedman and Kuttner, 1996, or Taylor, 1998). Several empirical studies have highlighted this shift in the conduct of U.S. monetary policy. Specifically, Clarida et al. (2000), who estimated a forward-looking reaction function for the federal funds rate, established a significant difference in the way the federal funds rate has responded to changes in macroeconomic indicators. Hence, we aim to unveil if there is a corresponding shift in the way the Federal Reserve has adjusted the supply of nonborrowed reserves.

Table 1 summarizes the estimated coefficients for the nonborrowed reserves equation in the reduced form of the VAR. According to the full sample estimation, the lags of real GDP, the implicit GDP deflator, the commodity price index and the federal funds rate are not statistically significant at conventional significance levels. Hence, for the full sample a significant relationship between nonborrowed reserves and the macroeconomic variables of interest cannot be established. Turning to the subsamples, two distinct results are noteworthy as they matter for the estimations that follow in the next section. The first main result relates to the commodity price index, both lags of which are found to be negative, but not significant during the pre-Volcker period. This stands in contrast to the Volcker-Greenspan era, where the first lag of the commodity price is negative and statistically significant. Since the commodity price index can be considered as an indicator for future inflation, our finding indicate that the Federal Reserve has responded to higher expected future inflation rates during the Volcker-Greenspan era, while they have been less relevant for money supply in the pre-Volcker era. Notably, the implicit GDP deflator is found to have no statistical impact on nonborrowed reserves in both sub-samples. Finally, the federal funds rate is found to be statistically insignificant in both sub-samples.

Table 1: VAR Estimation

Panel A: Full Sample Period: 1960 Q1 to 1999 Q4

NBR_t	Y_{t-1}	Y_{t-2}	P_{t-1}	P_{t-2}	CP_{t-1}	CP_{t-2}	FF_{t-1}
	-0.42	0.34	0.09	-0.02	-0.001	-0.0001	-0.004
	(0.25)	(0.26)	(0.49)	(0.49)	(0.0007)	(0.001)	(0.003)
	FF_{t-2}	NBR_{t-1}	NBR_{t-2}	TR_{t-1}	TR_{t-2}	c	R^2
	0.002	0.51*	-0.004	0.79*	-0.31*	0.52*	0.99
	(0.002)	(0.13)	(0.13)	(0.15)	(0.15)	(0.18)	

Panel B: Pre-Volcker Period: 1960 Q1 to 1979 Q2

NBR_t	Y_{t-1}	Y_{t-2}	P_{t-1}	P_{t-2}	CP_{t-1}	CP_{t-2}	FF_{t-1}
	-0.17	0.21	1.07	-1.01	-0.001	-0.001	0.002
	(0.27)	(0.28)	(0.91)	(0.91)	(0.001)	(0.001)	(0.005)
	FF_{t-2}	NBR_{t-1}	NBR_{t-2}	TR_{t-1}	TR_{t-2}	c	R^2
	-0.003	1.16*	-0.35	-0.33	0.39	0.83	0.99
	(0.004)	(0.20)	(0.19)	(0.24)	(0.35)	(0.65)	

Panel C: Volcker-Greenspan Period: 1982 Q4 to 1999 Q4

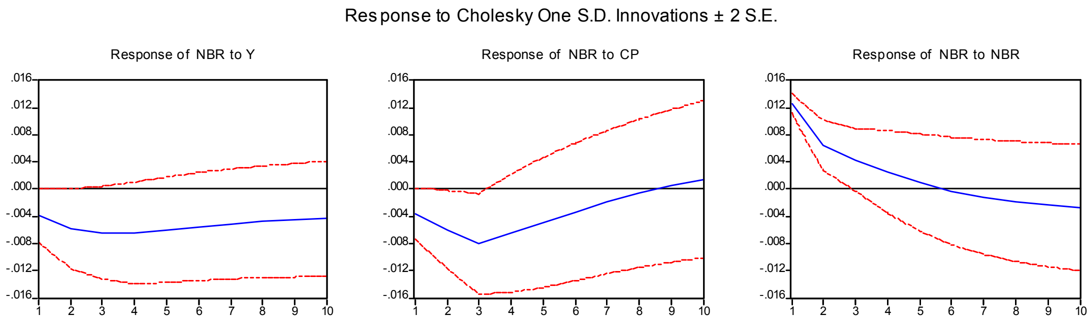
NBR_t	Y_{t-1}	Y_{t-2}	P_{t-1}	P_{t-2}	CP_{t-1}	CP_{t-2}	FF_{t-1}
	-1.57*	1.51*	-0.79	0.74	-0.003*	0.001	-0.008
	(0.56)	(0.56)	(1.36)	(1.36)	(0.001)	(0.001)	(0.005)
	FF_{t-2}	NBR_{t-1}	NBR_{t-2}	TR_{t-1}	TR_{t-2}	c	R^2
	0.001	0.71	0.06	0.49	-0.29	1.16*	0.99
	(0.005)	(0.48)	(0.45)	(0.49)	(0.44)	(0.56)	

Notes: Above numbers describe the estimated VAR-coefficients for the non-borrowed reserves equation. Figures in parentheses below coefficient estimates denote standard errors. c denotes a constant and R^2 denotes the coefficient of determination. Coefficients which are significant at the 5 percent level are marked with "*". p-values.

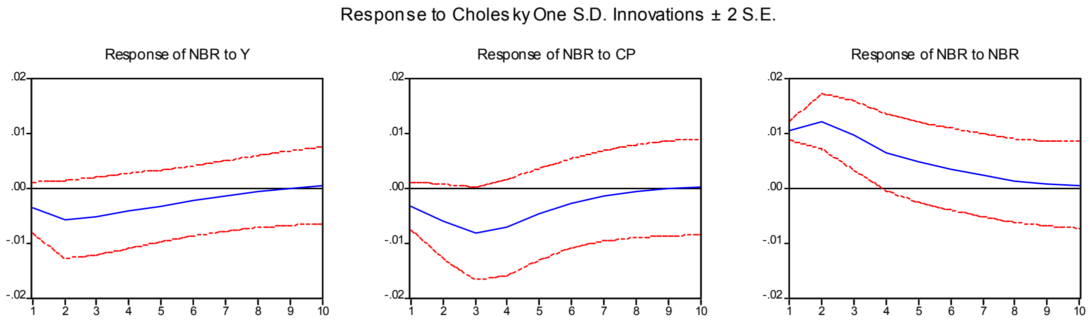
Though, these estimates already show remarkable differences in the behavior of nonborrowed reserves in post-war U.S. data, the nonborrowed reserves equation is usually not literally interpreted as a monetary policy reaction function. In particular, structural identifications schemes are further applied to identify exogenous monetary policy shocks. A specific identification scheme, which is for example used by Christiano et al. (1999), is based on a Cholesky decomposition combined with an Wold ordering of the variables where nonborrowed reserves can react to contemporaneous changes in the remaining variables.[5] To demonstrate how the responses of nonborrowed reserves changed over time, we adopt this particular identification scheme and compute impulse responses to innovations in macroeconomic variables.

Figure 1: Responses of Nonborrowed Reserves

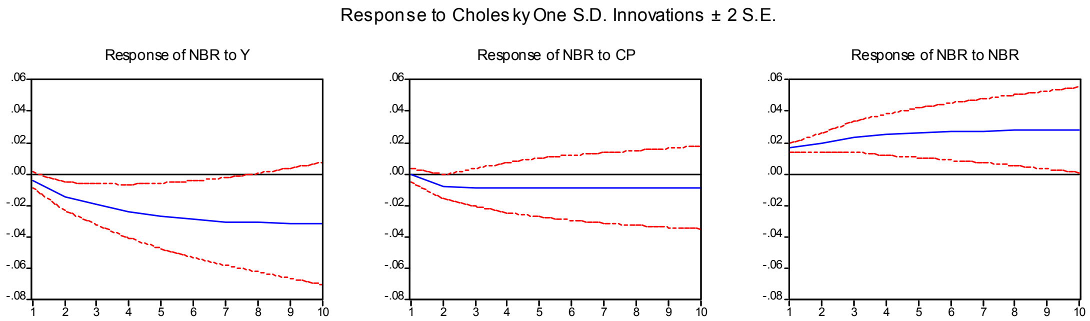
Panel A: Full Sample Period: 1960 Q1 to 1999 Q4



Panel B: Pre-Volcker Period: 1960 Q1 to 1979 Q2



Panel C: Volcker-Greenspan Period: 1982 Q4 to 1999 Q4



[5] This relates to Strongin's (1995) identification scheme, where a monetary policy shock is measured as the innovation to the ratio of nonborrowed to total reserves. The idea being that total reserves initially do not change as borrowed reserves adjust to changes in nonborrowed reserves.

Figure 1 presents impulse responses of nonborrowed reserves to innovations in variables which have significantly contributed to the evolution of nonborrowed reserves in the reduced form (Y, CP, and NBR).[6] Overall, the point estimates suggest that the supply of nonborrowed reserves has been reduced in response to positive innovations in real activity and in the commodity prices. Yet, the first column shows that only in the Volcker-Greenspan period nonborrowed reserves responded to changes in real activity in a significant way.[7] This difference is less pronounced for the responses to commodity price innovations (second column), though the point estimates suggest a more persistent response in the Volcker-Greenspan period. Finally, nonborrowed reserves always exhibit a significant and positive response to own innovations, while the persistence is most pronounced in the Volcker-Greenspan period.

2.2 Money supply reaction functions

The VAR estimates already disclose differences in Federal Reserve money supply adjustments between the pre- and the post-1979 periods. In order to get a clearer view on the systematic part of money supply we apply a single equation approach, which is now widely used to measure systematic central bank adjustments of a short-run interest rate. Specifically, we estimate a reaction function for the growth rate of nonborrowed reserves, which closely relates to the specification of the reaction function for the federal funds rate in Clarida et al. (2000). Thus, we assume that the growth rate of nonborrowed reserves responds to expected inflation and the output-gap in the following way:

$$\mu_t = \rho\mu_{t-1} + \mu_\pi E_t\left\{\pi_{t+n}\right\} + \mu_y x_t + \varepsilon_t, \tag{1}$$

where μ_t denotes the annualized growth rate of nonborrowed reserves, x_t the output-gap measure, and $E_t\left\{\pi_{t+n}\right\}$ is the expected inflation rate in $t+n$. The error term ε_t is assumed to be independently and identically distributed *(iid)* Gaussian.

The specification (1) evidently differs from the previous VAR-based specification. First, we chose a specification in growth rates, which allows for a more comprehensible interpretation of the estimated coefficients, but nonetheless is consistent with a log-level VAR specification. Second, the single-equation approach is based on a more parsimonious specification and omits the federal funds rate and total reserves. Since we were unable to establish a significant relationship between the federal funds rate and nonborrowed reserves in the reduced form of the VAR, the former is omitted in our specification. (Applying a corresponding specification where we included the federal funds rate, has led to

[6] We also computed impulse response functions of a monetary policy shock to the various economic aggregates. They are qualitatively similar to those reported in Christiano et al. (1999) and provide evidence in favour of a strong liquidity effect. Impulse responses are not reported but are available upon request.

[7] The dotted lines present a two standard error band, computed with the Monte Carlo method, spanning a 95% confidence interval.

an insignificant coefficient for the latter.) Third, unlike in the VAR approach, where the impact of expected future inflation is indirectly considered by the commodity price index, expected inflation is now modelled explicitly. Fourth, in line with interest rate feedback rules output-gap instead of output is considered as an additional explanatory variable. Finally, we chose the narrowest monetary aggregate and carry out all estimations using nonborrowed reserves as opposed to nonborrowed reserves plus credit, which has been used in the previous section and in by Christiano et al. (1999).

We first estimate (1) over a sample period which spans forty years of Federal Reserve policy. All data are obtained from the Federal Reserve Bank of St. Louis and are of quarterly frequency, spanning the horizon 1960:1-1999:4. Our benchmark inflation measure is based on the GDP deflator and is defined as the annualized percentage change in the price level between two subsequent quarters. Alternatively, we also consider consumer price inflation. Output gap is defined as the percent deviation between actual GDP and potential GDP as constructed by the Congressional Budget Office (CBO). We additionally allow for two alternative output-gap measures: (a) deviation of (log) GDP from a fitted quadratic function of time; and (b) the deviation of the unemployment rate from a similar time trend. For the future inflation rate we consider a horizon of one quarter in our benchmark estimations ($n = 1$). We further allow for longer inflation horizons and also report estimates based on a forward-looking horizon of four quarters ($n = 4$).

A widely used technique for estimating an equation of above nature is Generalized Method of Moments (GMM). The starting point of any GMM estimation is a theoretical relation that the parameters should satisfy, which is described by orthogonality conditions between some function of the parameters $f(\theta)$ and a set of instrumental variables z_t:

$$E_t\left(f(\theta)\, z_t\right) = 0, \tag{2}$$

where θ contains the parameters to be estimated. Let $f(\theta) = \mu_t - \rho\mu_{t-1} - \mu_\pi E_t\left\{\pi_{t+n}\right\} - \mu_y x_t$ and assuming rational expectations we can write

$$E_t\left\{\left(\mu_t - \rho\mu_{t-1} - \mu_\pi\pi_{t+n} - \mu_y x_t\right) z_t\right\} = 0, \tag{3}$$

which provides the basis for estimating the parameter vector $\left(\rho, \mu_\pi, \mu_y\right)$.[8] For all estimations the vector of instruments includes four lags of the growth rate of nonborrowed reserves, output-gap, and inflation. Since not all current information may be available to the public at the time they form expectations, contemporary variables are not used as instruments.

The estimation results for the full sample summarized in Table 2. All specifications are associated with a significant and pronounced autocorrelation coefficient ρ. Turning to

[8] The parameter estimates are obtained using a criterion function, that is of the following nature: $J(\theta) = (f(\theta)\, z)'\, W\, (f(\theta)\, z)$, where W is a weighting matrix.

the output-gap, a widening of the output-gap leads to a negative response in the supply of nonborrowed reserves. The estimated coefficient μ_y is statistically significant and lies in a range between -0.25 for the inflation rate based on the GDP deflator and -0.29 for CPI inflation. In contrast, there is no statistically significant relationship between the growth rate of nonborrowed reserves and expected inflation for a broad range of inflation measures over the full sample period. While the estimated coefficient μ_π on expected inflation is positive, albeit close to zero, it is not found to be statistically significant. A conventional view on monetary policy, would certainly suggest a negative relationship between the supply of nonborrowed reserves and expected inflation. Higher expected inflation should induce a stabilizing monetary policy to reduce the supply of nonborrowed reserves. The above reported estimation results, however, seem to proof us wrong. An explanation for this finding relates to the considered sample period, which does not distinguish between distinct periods of Federal Reserve policy. We thus continue by carrying out estimations for the money supply reaction function for these two sub-samples.

Table 2. Estimation Results for the Sample Period: 1960 - 1999

	GDP Deflator		*CPI*		*Greenbook*	
	$n = 1$	$n = 4$	$n = 1$	$n = 4$	$n = 1$	$n = 4$
$\widehat{\rho}$	0.88*	0.89*	0.88*	0.88*	0.90*	0.91*
	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)
$\widehat{\mu}_\pi$	0.07	0.06	0.04	0.04	0.03	-0.04
	(0.06)	(0.06)	(0.04)	(0.05)	(0.06)	(0.08)
$\widehat{\mu}_y$	-0.25*	-0.26*	-0.29*	-0.29*	-0.75*	-0.45
	(0.11)	(0.11)	(0.11)	(0.11)	(0.28)	(0.32)
R^2	0.70	0.70	0.70	0.70	0.44	0.60
J	0.62	0.61	0.58	0.57	0.69	0.69

Notes: Figures in parentheses below coefficient estimates denote standard errors. Coefficients which are significant at the 5 percent level are marked with "*". R^2 denotes the coefficient of determination; J is a test statistic for the null hypothesis that the overidentifying restrictions are satisfied. For the latter we only report p-values.

The first period we examine, covers the time horizon 1960:01 to 1979:2 and is referred to as the pre-Volcker era. We further explore monetary policy in the Volcker-Greenspan era, which covers the time horizon 1982:4 to 1999:4.[9] Table 3 summarizes the results

[9]Although Volcker was appointed Chairman of the Board of Governors of the Federal Reserve System in 1979, we refrain from including the first three years of his mandate in the sample period because this might lead to biased estimates for the Volcker-Greenspan period (see Clarida et al. 2000). Indeed, for a brief period at the start of the Volcker era, the Fed seemed to pursue a policy of non-borrowed reserves targeting (see Goodfriend, 1991).

for the pre-Volcker period. The feedback from changes in the output-gap is again negative and significant. Notably, the estimated coefficient $\widehat{\mu}_\pi$ on forward-looking inflation is significantly *positive*, suggesting that monetary policy during the pre-Volcker period was accommodating - higher expected inflation led to an increase in the money supply. Our findings are not sensitive to the chosen inflation measure with $\widehat{\mu}_\pi$ varying between 0.11 and 0.24. The feedback from expected future inflation on the growth rate of the monetary aggregate is always positive, though it is less pronounced for longer horizons ($n = 4$).

Table 3. Estimation Results: Pre-Volcker Period

	GDP Deflator		*CPI*	
	$n=1$	$n=4$	$n=1$	$n=4$
$\widehat{\rho}$	0.72*	0.72*	0.74*	0.75*
	(0.04)	(0.04)	(0.06)	(0.06)
$\widehat{\mu}_\pi$	0.24*	0.22*	0.11*	0.08
	(0.06)	(0.06)	(0.05)	(0.05)
$\widehat{\mu}_y$	−0.49*	−0.52*	−0.37*	−0.32
	(0.18)	(0.19)	(0.20)	(0.22)
R^2	0.52	0.52	0.54	0.53
J	0.77	0.77	0.65	0.61

Notes: See notes to Table 2.

Table 4 provides results obtained from estimating (1) using data for the Volcker-Greenspan period. The most striking result discovered for this period concerns the inflation elasticity, which is now found to be significantly negative at all inflation measures and inflation target horizons. Thus, monetary policy as measured by a forward-looking money supply reaction function appeared to be more reactive during the investigated period. This finding corresponds to earlier results on the federal funds rate behavior where the Volcker-Greenspan era is found to exhibit more aggressive (anti-inflationary) interest rate adjustments (see Boivin 2004, Boivin and Giannoni, 2003, and Clarida et al., 2000). The reported estimates for μ_π range between -0.35 and -0.62. Unlike in the pre-Volcker period, the supply of nonborrowed reserves now reacts somewhat stronger to expected inflation under a one year forward looking inflation horizon, suggesting that the Federal Reserve has focussed on longer target horizons. Estimates of μ_y indicate that the responses of nonborrowed reserves to the cyclical variable in both sub-periods are of comparable size. In fact, the average value for $\widehat{\mu}_y$ equals -0.51 (-0.34) for the GDP deflator (CPI) in the pre-Volcker period, which compares to a value of -0.60 (-0.27) for the Volcker-Greenspan period.

In general, the goodness-of-fit statistics are satisfactory for both subsamples, with the coefficient of determination ranging from 0.52 for the pre-Volcker period to 0.73 for the Volcker-Greenspan era. Hansen's J-test, which tests the validity of overidentifying restrictions, indicates that overall the null hypothesis that overidentifying restrictions are satisfied could not be rejected.

Table 4. Estimation Results: Volcker-Greenspan Period

	GDP Deflator		*CPI*	
	$n = 1$	$n = 4$	$n = 1$	$n = 4$
$\widehat{\rho}$	0.91*	0.92*	0.95*	0.98*
	(0.02)	(0.03)	(0.07)	(0.05)
$\widehat{\mu}_\pi$	−0.35*	−0.39*	−0.55*	−0.62*
	(0.15)	(0.14)	(0.05)	(0.05)
$\widehat{\mu}_y$	−0.62*	−0.59*	−0.15*	−0.39*
	(0.14)	(0.13)	(0.04)	(0.07)
R^2	0.73	0.73	0.69	0.71
J	0.92	0.95	0.80	0.76

Notes: See notes to Table 2.

We also carried out sub-sample estimations of (1) based on two alternative output-gap measures as described above. Our findings, which are summarized in Table A1 and A2 (see appendix), illustrate the robustness of our benchmark results as reported in Table 2 and 3. In fact, both the signs and magnitudes of the estimated coefficients remain broadly unchanged. In line with our baseline estimates, there remains the striking subsample difference in the coefficient measuring the sensitivity of nonborrowed reserves to expected inflation: In the pre-Volcker period the coefficient $\widehat{\mu}_\pi$ only takes positive values, while it is always negative in the Volcker-Greenspan period.[10]

2.3 Real-Time Estimates

Our previously reported results indicate the robustness of the sub-sample findings across different specifications including alternative inflation and output-gap measures and different target horizons. To further assess the robustness of our results we examine how the conduct of monetary policy under real-time data. Studies by Boivin (2004) and Orphanides (2001, 2002) have recently argued that the assessment of monetary policy based on *ex post* data produces a blurry picture, as central bankers are constrained by real-time information. Orphanides (2002), applying real-time data to a forward-looking interest rate

[10] We additionally conducted the estimations using non-borrowed reserves plus credit as the monetary aggregate. The results are qualitatively similar to our benchmark results. They are available from the authors upon request.

reaction function, offers intriguing evidence that monetary policy during the pre-Volcker era was not accommodative at all but responded strongly to inflation forecasts. This finding evidently contrast those reported by Clarida et al. (2000).

A set of inflation forecasts suitable for analyzing the nature of real-time U.S. monetary policy is drawn from the so-called Greenbook. Greenbook forecasts are prepared by the staff of the Board of Governors for the meetings of the FOMC and have been used in a number of studies.[11] Using the Greenbook forecasts in this context yield some important benefits. First, these forecasts are generated using information that was actually available at the time monetary policy decisions were made, providing a more precise view on monetary policy decisions. Second, since Greenbook forecasts are computed using a large set of information from a wide range of sources, the Fed forecasts might have an informational advantage over private sector forecasts. In fact, Romer and Romer (2000) and Faust et al. (2003) have documented that Greenbook forecasts are exceptionally accurate compared to private-sector forecasts, suggesting that the Fed has information which may not be accessible to the public.[12] Finally, since Greenbook forecasts account for possible structural changes of the economy, the time-varying nature of monetary policy is better described, making the analysis less susceptible to the Lucas critique as emphasized by Boivin (2004).

The first Greenbook forecasts were published in 1965. One shortcoming of the early forecasts is that observations were not consistently available and forecasts for longer horizons were not produced. Hence, for practical reasons our sample period covers the time horizon from the first quarter of 1968 to the last quarter of 1999. Forecasts beyond the fourth quarter of 1999 are not made available yet as they are published with a five year lag. Using the Greenbook forecasts we estimate the structural relationship described by (1) for the pre-Volcker and Volcker-Greenspan era. The instruments used for the estimation again include four lags of the growth rate of nonborrowed reserves, output-gap and inflation based on the GDP-deflator.

In accordance with our previous findings, the growth rate of nonborrowed reserves reacts positively to rising inflation forecasts in the pre-Volcker era and negatively in the Volcker-Greenspan period, while the feedback from the real-time output-measure is always negative (see Table 5). Overall, these estimates clearly confirm the existence of a shift in the conduct of U.S. monetary policy. These results contrast those reported in Orphanides (2002), who (using real-time data to estimate forward looking interest rate rule) does not detect a substantial shift in structural part of U.S. post war monetary policy.

[11] See Giannoni et al. (2005), Boivin (2004, 1999), Orphanides (2001, 2002), and Romer and Romer (2003) to name a few. Information on the construction of these forecasts can be found in Reifschneider et al. (1997) who emphasize that forecasts are conditioned on an assumed path for the federal funds rate. Moreover, unlike other forecasts, which are often derived on the basis of econometric forecasting models, Greenbook forecasts comprise a large "judgmental" component.

[12] Moreover, Swanson (2004) assessing the Greenbook forecasts finds that the Fed's projections are largely rational.

Table 5. **Estimation Results based on Greenbook Forecasts**

	Pre-Volcker		Volcker-Greenspan	
	$n = 1$	$n = 4$	$n = 1$	$n = 4$
$\widehat{\rho}$	0.56*	0.30*	0.87*	0.85*
	(0.03)	(0.02)	(0.03)	(0.05)
$\widehat{\mu}_\pi$	0.12*	0.03	−0.20*	−0.25*
	(0.05)	(0.05)	(0.08)	(0.06)
$\widehat{\mu}_y$	−1.79*	−1.82*	−0.84*	−0.63*
	(0.14)	(0.15)	(0.18)	(0.14)
R^2	0.62	0.48	0.70	0.71
J	0.94	0.96	0.76	0.76

Notes: Due to unavailability of real-time data, the sample for the pre-Volcker period starts in 1968:03 for n=1 and 1974:02 for n=4.

Real-time data clearly attribute a stronger role to the shorter inflation forecast horizon during the pre-Volcker era, while the longer forecast horizon becomes more important during the Volcker-Greenspan period. Notably, we observe a much stronger feedback from the output-gap for real-time data. This difference in the estimated output-gap coefficients between real-time and ex-post data might be due to the distorted estimation of the trend component of output (see Orphanides, 2002). These misperceptions about the trend component lead to a mismeasurement of the output-gap, which, if persistent over a period of time, might result in biased output-gap coefficients. Finally, our estimates indicate that ex-post data overstate the (absolution value of the) inflation elasticity. In fact, the real-time estimates suggest that the Fed was less accommodating during the pre-Volcker era, while the anti-inflationary stance during the Volcker-Greenspan period was not as emphasized as the ex-post data based estimations suggest.

To summarize, the empirical analysis provides strong evidence for the supply of non-borrowed reserves to react systematically to expected inflation and the output-gap during the past four decades of Federal Reserve policy. The empirical results further indicate that monetary policy during the Volcker-Greenspan era had a proactive stance towards inflation stabilization. Our findings thus seem to be consistent with the results in Clarida et al. (2000) who characterize the Volcker-Greenspan era as a highly reactive monetary policy regime. Conversely, in the pre-Volcker period, supply of nominal balances appeared to be mildly accommodating, lending support to the view that the Fed had a less anti-inflationary stance though aimed to stabilize output during that period. These main results are further robust to changes in the way expectations are modelled, i.e., the results are qualitatively unaffected when we apply real-time data as opposed to ex post data to describe the behavior of U.S. money supply.

3 Money supply and macroeconomic stability

In this section we apply a simple model in order to assess macroeconomic stability when the central bank supplies money according to reaction functions of the type used in the empirical analysis in section 2.2. In the first part of this section we present the model and briefly describe the properties of an optimal money supply. In the second part we derive the requirements of equilibrium stability and uniqueness under forward-looking money supply reaction functions.

3.1 A simple sticky price model

In order to facilitate comparisons with recent studies on macroeconomic stability under interest rate feedback rules, we use a standard New Keynesian model (see Clarida et al., 2000). As for example shown by McCallum and Nelson (1999) it can be derived from a dynamic general equilibrium model with optimizing households and firms under rational expectations. Non-neutrality of monetary policy is induced by an imperfectly flexible price setting of monopolistically competitive firms which produce intermediate goods. Log-linearizing the first-order conditions of households and firms (and using aggregate production and market clearing conditions) leads to the so-called forward-looking AS and AD curve (see below).

While money demand is often disregarded when the central bank is assumed to control the nominal interest rate, it can evidently not be neglected for our purpose. In order to disclose the main principles for the impact of money supply on macroeconomic stability, we impose some simplifying assumptions regarding the demand for central bank money. Firstly, we assume that the stock of monetary aggregates M_t that provide transactions services in the goods market is tied to the stock of high-powered money H_t. In particular, we assume that the money multiplier is stable. Since we focus on the structural relations between money supply and macroeconomic aggregates, we disregard money demand shocks in what follows. Hence, in log-linearized form the real values of both aggregates are simply linked by $\widehat{m}_t = \widehat{h}_t$, where $\widehat{x}_t$ denotes the percent deviation of a generic variable x_t from its steady state value x, $\widehat{x}_t = (x_t - x)/x$, and $m_t = M_t/P_t$, where P denotes the aggregate price level.

We consider two types of money demand specifications. Firstly, we apply a simplified specification for money demand where total nominal expenditures E_t are proportional to holdings of cash M_t. Hence, this specification, which is often used to abstract from money demand distortions induced by interest rate changes (see for example King and Wolman, 2004), implies a unit income elasticity of money demand and reads in log-linear form $\widehat{m}_t = \widehat{e}_t$. It can either be interpreted as a quantity equation, or as a binding cash-in-advance constraint. The latter, however, often leads to a distortion between cash and credit goods consumed by households. In order to avoid these types of interest rate distortions, which are for example also disregarded by Clarida et al. (2000), it can be assumed that the cash constraint applies to all goods which are consumed by households (see Jeanne, 1998, or appendix 5.2).[13] Secondly, we consider an interest elastic money demand which can for example be derived from money entering a separable utility function. To get a unit income elasticity, the intertemporal elasticities of substitution for money and consumption are assumed to be equal. Money demand then reads in log-linear form $\widehat{m}_t = \widehat{y}_t - \gamma \widehat{R}_t$, where $\gamma > 0$.

For the subsequent analysis we use a model which has been log-linearized at the steady state. For this, we assume that the nominal interest rate R_t is always strictly larger than one, and that the support of aggregate shocks is sufficiently small. We further assume that uncertainty is due to distortionary cost-push shocks (that for example originate in exogenous shifts in price or wage mark-ups), such that output equals the output-gap $\widehat{x}_t$. A *rational expectations equilibrium* consists of a set of sequences for inflation ($\pi_t = P_t/P_{t-1}$), output-gap, real money, the growth rate of nominal money $\widehat{\mu}_t$, and the nominal interest rate, $\{\widehat{\pi}_t, \widehat{x}_t, \widehat{m}_t, \widehat{\mu}_t, \widehat{R}_t\}_{t=0}^{\infty}$, satisfying

$$\widehat{\pi}_t = \omega \widehat{x}_t + \beta E_t \widehat{\pi}_{t+1} + \chi \widehat{\varphi}_t, \tag{4}$$

$$\sigma \widehat{x}_t = \sigma E_t \widehat{x}_{t+1} - (\widehat{R}_t - E_t \widehat{\pi}_{t+1}), \tag{5}$$

$$\widehat{m}_t = \widehat{x}_t - \gamma \widehat{R}_t, \tag{6}$$

(where $\sigma \geq 1$, $\omega > 0$, $\chi > 0$, and $\gamma \geq 0$), $\widehat{\mu}_t = \widehat{m}_t - \widehat{m}_{t-1} + \widehat{\pi}_t$, a state contingent reaction function for the money growth rate $\widehat{\mu}_t$, and the households' transversality condition, for a given sequences of cost-push shocks $\{\widehat{\varphi}_t\}_{t=0}^{\infty}$ and an initial value $m_{-1} = M_{-1}/P_{-1}$. Note that the intertemporal elasticities of substitution for money and consumption are equal and given by $1/\sigma$.

3.2 Efficient money supply

Before we turn to the analysis of macroeconomic stability under the type of forward-looking money supply reaction functions used in the empirical analysis, we want to assess how an efficient money supply looks like. To obtain a transparent result, we apply the simple money demand specification $\gamma = 0 \Rightarrow \widehat{m}_t = \widehat{y}_t$. As shown by Woodford (2003), social welfare can be approximated by a quadratic loss function by applying a second-order Taylor expansion of the non-linear equilibrium conditions and household welfare at the undistorted steady state, $-\Xi \frac{1}{2} E_0 \sum_{t=0}^{\infty} \beta^t \left(\widehat{\pi}_t^2 + \frac{\omega}{\epsilon} \widehat{x}_t^2 \right)$, where $\Xi > 0$ and $\epsilon > 1$ denotes the elasticity of substitution between differentiated intermediate goods. We assume that the central bank maximizes social welfare subject to the aggregate supply constraint (4) under commitment in a timeless perspective (see Woodford, 2003). The optimal plan of the central bank is then known to be characterized by (4)-(6) and the first order condition

[13] When the cash-credit good distortion is not eliminated, the nominal interest rate would enter the AS curve, i.e., the forward-looking Phillips curve (see Schabert, 2005).

$\widehat{x}_t - \widehat{x}_{t-1} = -\epsilon\widehat{\pi}_t \; \forall t \geq 0$. Using $\widehat{m}_t = \widehat{x}_t$ and $\widehat{\mu}_t = \widehat{m}_t - \widehat{m}_{t-1} + \widehat{\pi}_t$, immediately shows that an optimal money growth rate has to satisfy $\widehat{\mu}_t = (1-\epsilon)\widehat{\pi}_t$. Thus, a central bank can implement its optimal commitment plan under a timeless perspective by reducing the supply of money in response to changes in inflation according to

$$\widehat{\mu}_t = \mu_\pi^* \widehat{\pi}_t, \quad \text{where} \;\; \mu_\pi^* = -(\epsilon - 1) < 0. \tag{7}$$

Thus, the simple result on optimal money supply summarized by (7) implies that a constant or even a positive inflation feedback is evidently suboptimal. The sign restriction $\mu_\pi^* < 0$ relates to the main difference between the estimated reaction functions presented in section 2.2. While the pre-Volcker era was associated with a positive inflation feedback, Federal Reserve policy in the Volcker-Greenspan era has led to a negative inflation feedback. Given this clear evidence, we can immediately conclude that money supply of the latter regime more successfully stabilizes macroeconomic fluctuations induced by fundamental shocks and leads to higher social welfare.

3.3 Money supply and macroeconomic stability

We now want to examine the local dynamic properties of the model under the type of forward-looking money supply reaction functions used in the empirical analysis. Thus, this analysis corresponds to Clarida et al.'s (2000) stability analysis for interest rates rules in an identical model. For this purpose, the central bank is assumed to supply money according to the following inertial reaction function

$$\widehat{\mu}_t = \rho\widehat{\mu}_{t-1} + \mu_\pi E_t \widehat{\pi}_{t+n} + \mu_y \widehat{x}_t, \quad \text{where } n \in \{0, 1\}. \tag{8}$$

It should be noted that we do not consider the case where the target horizon equals four quarters, $n = 4$, for convenience Instead we examine the cases where money supply either responds to the current inflation rate ($n = 0$) or the one-period ahead expected rate of inflation ($n = 1$). Thus, the cases under consideration correspond to specifications typically used for the stability and uniqueness implications of interest rate rules (see Clarida et al., 2000, Carlstrom and Fuerst, 2001, or Woodford, 2003).

We start our analysis with the simple case where money demand satisfies $\gamma = 0 \Rightarrow \widehat{m}_t = \widehat{x}_t$. The set of equilibrium conditions can then be reduced to the three conditions $\widehat{\pi}_t = \omega\widehat{m}_t + \beta E_t \widehat{\pi}_{t+1} + \widehat{\varphi}_t$, $\widehat{\mu}_t = \widehat{m}_t - \widehat{m}_{t-1} + \widehat{\pi}_t$, and (8). Thus, the model exhibits (for $\rho \neq 0$) two backward-looking elements, i.e., the predetermined state variables $\widehat{\mu}_{t-1}$ and $\widehat{m}_{t-1}$. Existence and uniqueness of locally stable equilibrium sequences therefore require that there are exactly two stable eigenvalues. It can be shown that the existence of two positive and stable eigenvalues requires a money supply reaction function (8) for $n = 1$ and $n = 0$ to satisfy

$$\mu_\pi + \mu_y \frac{1-\beta}{\omega} < 1 - \rho \tag{9}$$

The condition (9) demands the weighted sum of the feedback coefficients in (8) to be smaller than $1/(1-\rho)$. Put differently, (9) requires the weighted sum of the long-run coefficients $\mu_\pi/(1-\rho)$ and $\mu_y/(1-\rho)$ has to be smaller than one. This requirement relates to the well known Taylor-principle which requires the weighted sum of the long-run coefficients of an interest rate feedback rule to be larger than one (see Woodford, 2001). It should, however, be noted that condition (9) is just a necessary condition for the existence of two positive stable roots, which implies that equilibrium sequences are stable and non-oscillatory. Hence, there might also exist stable oscillatory equilibrium sequences where there is one stable and one unstable eigenvalue.

To get an intuition for the main principle consider the simplifying case $\rho = \mu_y = 0$. Then money supply can be associated with unstable (or multiple stable non-oscillatory) equilibrium sequences when μ_π is larger than one. Suppose, for example, that a cost push shock $\widehat{\varphi}_t > 0$ leads to a rise in inflation, which reduces the real value of money for $\mu_\pi < 1$. In this case, aggregate demand declines bringing inflation back to its steady state value. Otherwise, $\mu_\pi > 1$ causes real balances and, thus, aggregate demand to grow, which further leads to an upward pressure on prices.

The following proposition provides conditions uniqueness and stability are given in the following proposition. It should be noted that these conditions are sufficient (but not necessary) for equilibrium stability and uniqueness.

Proposition 1 *Suppose that money demand satisfies $\widehat{m}_t = \widehat{x}_t$ and money supply satisfies (8).*

1. *For $n = 1$, the equilibrium sequences are locally stable and uniquely determined if (9), $\mu_y(1+\beta) - \omega(1+\rho+\mu_\pi) < 2((1+\beta)(1+\rho))$ and $\beta(1-\mu_y) + \omega\mu_\pi > \rho$. The equilibrium sequences are then non-oscillatory.*

2. *For $n = 0$, the equilibrium sequences are locally stable and uniquely determined if (9), $\omega\mu_\pi + \mu_y(1+\beta) < (1+\rho)(\omega + 2(1+\beta))$ and $\beta(1-\mu_y) > \rho$. The equilibrium sequences are then non-oscillatory.*

Proof. See appendix 5.3.

Having established the stability conditions for a simple money demand specification ($\widehat{m}_t = \widehat{x}_t$) and an inertial money supply reaction function ($\rho > 0$), we now examine the case where money demand is interest rate elastic, $\gamma > 0$. Since the model would then exhibit a characteristic polynomial of order four, we simplify the money supply function. In particular, we assume that it does not exhibit inertia, $\rho = 0$. For this case the model can be reduced to $\widehat{\pi}_t = \omega\widehat{x}_t + \beta\widehat{\pi}_{t+1} + \chi\widehat{\xi}_t$, $\left(\sigma + \gamma^{-1}\right)\widehat{x}_t = \sigma E_t\widehat{x}_{t+1} + \gamma^{-1}\widehat{m}_t + E_t\widehat{\pi}_{t+1}$, and $\widehat{m}_t = \widehat{m}_{t-1} - \widehat{\pi}_t + \mu_\pi E_t\widehat{\pi}_{t+1} + \mu_y\widehat{x}_t$. In this case, one can easily derive necessary and sufficient conditions for stability and uniqueness. The following proposition presents these conditions for $n = 1$ and $n = 0$.[14]

Proposition 2 *Suppose that money demand satisfies $\widehat{m}_t = \widehat{x}_t - \gamma \widehat{R}_t$ and money supply satisfies (8) and $\rho = 0$.*

1. *For $n = 1$, the equilibrium sequences are locally stable and uniquely determined if and only if (9) and $\mu_y (1+\beta) - \omega\mu_\pi < \omega + 2(\gamma\omega + (2\sigma\gamma + 1)(1+\beta))$. The equilibrium sequences are then non-oscillatory.*

2. *For $n = 0$, the equilibrium sequences are locally stable and uniquely determined if and only if (9) and $\mu_\pi + \mu_y (1+\beta)/\omega < 1 + 2((1+2\sigma\gamma)(1+\beta) + \gamma\omega)/\omega$. The equilibrium sequences are then non-oscillatory.*

Proof. See appendix 5.4.

Given the conditions in proposition 1 and 2 we can now easily assess whether money supply rules lead to instability or indeterminacy when the coefficients ρ, μ_π, and μ_y are set equal to the point estimates in section 2.2. For this we apply parameter values for the structural parameter σ and β, and for the reduced form parameter ω and γ. The only parameter value which is held constant is β, which is set equal to the (standard) value 0.99. For the remaining parameter we consider fairly wide ranges of values which clearly cover parameterizations that can be found in related literature.

Numerical results for the parameter values $\beta = 0.99$, $\sigma \in (0.01, 10)$, $\omega \in (0.01, 1)$, and $\gamma \in [0, 100)$.

1. Consider the case where money demand is given by $\widehat{m}_t = \widehat{x}_t$ and monetary policy satisfies (8). Then, money supply described by (significant) point estimates given in table 3 and 4 satisfy the conditions in proposition 1 and 2. Further, a money supply reaction function (8) characterized by the point estimates given in table 5 are also associated with a stable and unique equilibrium.

2. Consider the case where money demand is given by $\widehat{m}_t = \widehat{x}_t - \gamma \widehat{R}_t$ and monetary policy satisfies $\widehat{\mu}_t = \mu_\pi (1-\rho)^{-1} E_t \widehat{\pi}_{t+n} + \mu_y (1-\rho)^{-1} \widehat{x}_t$. Then, money supply described by (significant) point estimates given table 3, 4, and 5 satisfy the conditions in proposition 1 and 2.

Thus, we can summarize that when money supply is described by the point estimates in section 2, the rational expectations equilibrium is always uniquely determined and stable regardless whether we use the estimates for revised data or for real time data. Thus our

[14] The conditions in second part for $n = 0$ correspond to the conditions derived in Schabert (2005). Note that stability and uniqueness of equilibrium sequences now require the existence of exactly one stable eigenvalue.

analysis of the stability implications of money supply regimes in a simple sticky price model leads to a different conclusion than studies focussing on interest rate rules: Pre-Volcker Federal Reserve policy has not been associated with multiple equilibria and therefore did not allow for macroeconomic fluctuations induced by non-fundamental shocks.

The difference between the stability and real determinacy results for money growth and interest rate policy correspond to the property of nominal (in)determinacy under money growth (interest rate) policy, which has for example been examined by Sargent and Wallace (1975) or, more recently, by Carlstrom and Fuerst (2001, 2003). While a money growth policy facilitates nominal determinacy under perfectly flexible prices, it causes beginning-of-period real balances to be relevant for equilibrium determination when prices are not perfectly flexible. The predetermined value of real money then serves as a equilibrium selection criterion, which rules out solutions with extraneous states that would allow for endogenous fluctuations. While the stability results in previous studies refer to a constant money growth policy, the findings in this paper show that they continue to hold as long as (9) is satisfied. Concisely, Federal Reserve policy has never allowed for macroeconomic instability since the growth rate of *real* money (reserves) has always been decreasing in (expected) inflation.

4 Conclusion

In this paper we provide empirical evidence that the Federal Reserve money supply, i.e., the growth rate of nonborrowed reserves, has responded to changes in expected inflation and the output-gap. Estimates of forward-looking money supply reaction functions for the pre-1979 and the post-1979 period reveal that the latter regime has been highly reactive indicated by a significantly negative feedback from expected inflation (and the output-gap), whereas the former regime was in fact associated with an accommodating money supply, i.e., a significantly positive feedback from expected inflation. Thus our empirical analysis of the money supply supports related evidence based on the federal funds rate behavior, namely that the Federal Reserve policy in the pre-Volcker era has been conducted in a less stabilizing way than in the Volcker-Greenspan era. We further find that this difference is does not rely on the use of revised (in contrast to real time) data.

We further provide a theoretical analysis of the stability implications of money supply reaction functions in a standard sticky price model. We thereby find that money supply regimes characterized by the estimated reaction functions are associated with stable and uniquely determined rational expectations equilibria. According to this result, we cannot confirm the hypothesis of Clarida et al. (2000) that pre-Volcker policy has contributed to high and volatile inflation rates in the 1970's by failing to pin down the equilibrium allocation. Thus, viewed through a money supply lens Federal Reserve policy in the pre-1979 period has less successfully stabilized macroeconomic fluctuations caused by fundamental shocks, though it had not allowed for endogenous (non-fundamental) fluctuations.

5 Appendix

5.1 Estimates for alternative output-gap measures

Table A1. Estimation Results Based on Unemployment

	Pre-Volcker		Volcker-Greenspan	
	$n=1$	$n=4$	$n=1$	$n=4$
$\widehat{\rho}$	0.71*	0.71*	0.91*	0.90*
	(0.05)	(0.06)	(0.02)	(0.03)
$\widehat{\mu}_\pi$	0.12*	0.10	−0.34*	−0.31*
	(0.06)	(0.06)	(0.15)	(0.17)
$\widehat{\mu}_y$	−0.23	−0.23	−0.62*	−0.81*
	(0.25)	(0.34)	(0.14)	(0.26)
R^2	0.54	0.53	0.73	0.73
J	0.57	0.59	0.92	0.91

Notes: Estimations are conducted using the alternative output gap measure based on the deviation of unemplyoment rate from a fitted quadratic function of time. See notes to Table 1 and 3.

Table A2. Estimation Results based on Detrended Output

	Pre-Volcker		Volcker-Greenspan	
	$n=1$	$n=4$	$n=1$	$n=4$
ρ	0.73*	0.72*	0.91*	0.96*
	(0.04)	(0.04)	(0.04)	(0.03)
μ_π	0.24*	0.22*	−0.50*	−0.49*
	(0.06)	(0.06)	(0.17)	(0.17)
μ_y	−0.49*	−0.52*	−0.46*	−0.47*
	(0.18)	(0.19)	(0.15)	(0.14)
μ_π	0.89	0.78	−5.56	−12.25
R^2	0.53	0.52	0.72	0.72
J	0.42	0.42	0.92	0.95

Notes: Estimations are conducted using the alternative output gap measure based on the deviation of (log) GDP from a fitted quadratic function of time. See notes to Table 1 and 3.

5.2 Summary of the cash-in-advance model

In this appendix we briefly summarize the underlying general equilibrium set-up for the log-linear version of the model in (4), (4) and (6) for $\gamma = 0$. Throughout, nominal (real) variables are denoted by upper-case (lower-case) letters. There is a continuum of households indexed with $j \in (0,1)$. They are identical except for their idiosyncratic working time l_j. Hence, the indexation of households' variables with j can be omitted except for labor market variables. The objective of household j is

$$E_0 \sum_{t=0}^{\infty} \beta^t \left[\frac{c_t^{1-\sigma}}{1-\sigma} - \frac{l_{jt}^{1+\vartheta}}{1+\vartheta} \right], \quad \sigma, \vartheta > 0, \tag{10}$$

where c denotes consumption, $\beta \in (0,1)$ the subjective discount factor, and E_0 the expectation operator conditional on the information in period 0. At the beginning of each period households are endowed with money M_{t-1} and government bonds B_{t-1}. Households are assumed to hold checkable accounts at a financial intermediary. After goods are produced labor income is credited on this account, while it is charged for wage outlays of firms which are owned by the households. In the goods market expenditures are restricted by the following liquidity constraint:

$$P_t c_t \leq M_{t-1} + \left(P_t w_{jt} l_{jt} - P_t w_t \int_0^1 l_{it} di \right) + P_t \tau_t, \tag{11}$$

where $w_j(w)$ denotes the idiosyncratic (aggregate) real wage rate and τ_t denotes lump sum transfers. The conventional cash-in-advance constraint is augmented by allowing for net wage earnings, i.e., the term in round brackets in (11), to be accepted as a means of payment. Hence, an individual labor income, which exceeds the average wage payments of final goods producing firms indexed with $i \in (0,1)$ employing l_i, leads to an relaxation of the cash constraint (11). This assumption, which is adopted from Jeanne (1998), is introduced to avoid the cash-credit good distortion between consumption and leisure.

Labor input in production l_t is an aggregate of differentiated labor services $l_j : l_t^{1-1/\eta_t} = \int_0^1 l_{jt}^{1-1/\eta_t} dj$, where the elasticity of substitution between differentiated labor services η_t is allowed to vary exogenously over time. Cost minimization with respect to differentiated labor services then leads to following demand schedule for $l_j : l_{jt} = \left(\frac{w_{jt}}{w_t}\right)^{-\eta_t} l_t$ where $w_t^{1-\eta_t} = \int_0^1 w_{jt}^{1-\eta_t} dj$ and l denotes aggregate labor services. Households receive profits ω_t, wage payments, and a government transfer. The budget constraint of household j is

$$P_t c_t + B_t + M_t \leq R_t B_{t-1} + M_{t-1} + P_t w_{jt} l_{jt} + P_t \tau_t + P_t \omega_t, \tag{12}$$

where R_t denotes the gross nominal interest rate. Maximizing the objective (10) subject to the cash-in-advance constraint (11), the budget constraint (12), labor demand and a no-Ponzi-game condition, for given initial values B_{-1} and M_{-1} leads to

$$c_t^{-\sigma} = \lambda_t + \psi_t, \quad l_{jt}^{\vartheta}\varphi_t = (\lambda_t + \psi_t)\, w_{jt}, \tag{13}$$

$$\frac{1}{\beta}\lambda_t = E_t\left[\frac{R_{t+1}}{\pi_{t+1}}\lambda_{t+1}\right], \quad \frac{1}{\beta}\lambda_t = E_t\frac{\lambda_{t+1}}{\pi_{t+1}} + E_t\frac{\psi_{t+1}}{\pi_{t+1}}, \tag{14}$$

$\psi_t \geq 0$, $\psi_t[m_{t-1}\pi_t^{-1} + w_{jt}l_{jt} - w_t\int_0^1 l_{it}di - c_t + \tau_t] = 0$ and (11), where $\varphi_t = \frac{\eta_t}{\eta_t - 1}$ denotes the markup over the perfectly competitive real wage, λ the shadow price of wealth, ψ the Lagrange multiplier on the cash-in-advance constraint, $m_t = M_t/P_t$ real balances, and $\pi_t \equiv P_t/P_{t-1}$ the inflation rate. Furthermore, the budget constraint (12) holds with equality and the transversality condition $\lim_{i\to\infty} E_t\left[\lambda_{t+i}\beta^{t+i}\left(b_{t+i} + m_{t+i}\right)\right] = 0$ are satisfied. Note that there is no cash-credit distortion between consumption and leisure $c_t^{\sigma}l_t^{\vartheta} = w_{jt}/\varphi_t$.

The final good y_t is an aggregate of differentiated goods produced by monopolistically competitive firms indexed with $i \in (0,1)$: $y_t^{1-1/\epsilon} = \int_0^1 y_{it}^{1-1/\epsilon}di$, where $\epsilon > 1$ and y_i is the amount produced by firm i, and ϵ the constant elasticity of substitution between these differentiated goods. Let P_i and P denote the price of good i set by firm i and the price index for the final good. The cost minimizing demand for each differentiated good is $y_{it} = (P_{it}/P_t)^{-\epsilon}\, y_t$ where $P_t^{1-\epsilon} = \int_0^1 P_{it}^{1-\epsilon}di$. Differentiated goods y_i are produced by $y_{it} = l_{it}$. Prices are set according to Calvo's (1983) staggered price setting scheme. Each period firms may reset their prices with the probability $1-\phi$, while the fraction ϕ of firms do not change their prices. The linear approximation to the corresponding aggregate supply constraint at the steady state, is known to be given by

$$\widehat{\pi}_t = \chi\widehat{mc}_t + \beta E_t\widehat{\pi}_{t+1}, \qquad \text{with } \chi = (1-\phi)(1-\beta\phi)\,\phi^{-1} > 0, \tag{15}$$

Note that $\widehat{x}$ denotes the percent deviation from the steady state value $\overline{x}$ of a generic variable x, $\widehat{x} = \log(x_t) - \log(\overline{x})$, and mc the real marginal costs. The demand for aggregate labor input in a symmetric equilibrium relates the real marginal costs to the real wage: $mc_t = w_t$.

The public sector consists of a monetary and a fiscal authority. The latter is assumed to issue one-period bonds, earning the net interest $(R_t - 1)B_{t-1}$, while the former issues money. The consolidated flow budget constraint of the public sector is given by $B_t + M_t = R_tB_{t-1} + M_{t-1} + P_t\tau_t$, where $\lim_{i\to\infty}(B_{t+i} + M_{t+i})E_{t+i}\Pi_{v=1}^{i}\left(1 + i_{t+v}\right)^{-1} = 0$. Finally, the central bank is assumed to control the money growth rate $\mu_t = M_t/M_{t-1}$, in a way that is consistent with a steady state satisfying $\overline{R} = \overline{\pi}/\beta > 1$.

A *rational expectations equilibrium* consists of an allocation and a price system satisfying the household's first order conditions, the firms' price setting decisions and labor demand, aggregate production, the aggregate resource constraint, the transversality condition, and a monetary policy, for a given sequence for $\varepsilon_{\varphi t}$ where $\varphi_t = \overline{\varphi}^{1-\rho_\varphi}\varphi_t^{\rho_\varphi}\exp(\varepsilon_{\varphi t})$, $\overline{\varphi} > 1$ and $\varepsilon_{\varphi t}$ are i.i.d. with $E_{t-1}\varepsilon_{\varphi t} = 0$, and initial values for M_{-1} and P_{-1}.

5.3 Proof to proposition 1

To proof the first part ($n = 1$) of the proposition, the deterministic version of the model with a money demand $\widehat{m}_t = \widehat{x}_t$ and money supply (8) is written as

$$\begin{pmatrix} \widehat{\pi}_{t+1} \\ \widehat{m}_t \\ \widehat{\mu}_t \end{pmatrix} = \mathbf{A} \begin{pmatrix} \widehat{\pi}_t \\ \widehat{m}_{t-1} \\ \widehat{\mu}_{t-1} \end{pmatrix}, \text{ where } \mathbf{A} = \begin{pmatrix} \beta & \omega & 0 \\ -\mu_\pi & -\mu_y & 1 \\ 0 & -1 & 1 \end{pmatrix}^{-1} \begin{pmatrix} 1 & 0 & 0 \\ 0 & 0 & \rho \\ 1 & -1 & 0 \end{pmatrix}.$$

The characteristic polynomial of $\mathbf{A}$, which is given by

$$H_{n=1}(X) = X^3 + X^2 \frac{\beta + \omega + \beta\rho - \mu_y + 1}{\beta\mu_y - \omega\mu_\pi - \beta} + X \frac{-\rho - \beta\rho - \omega\rho - 1}{\beta\mu_y - \omega\mu_\pi - \beta} + \frac{\rho}{\beta\mu_y - \omega\mu_\pi - \beta}.$$

takes the following values at 0, 1 and -1

$$\begin{aligned} H_{n=1}(0) &= -\rho/[(1-\mu_y)\beta + \omega\mu_\pi], \\ H_{n=1}(1) &= H(0)\rho^{-1}\left(\omega(1-\rho) - \omega\mu_\pi - \mu_y(1-\beta)\right), \\ H_{n=1}(-1) &= H(0)\rho^{-1}\left(2(\beta+\rho+\beta\rho+1) + \omega(1+\rho+\mu_\pi) - \mu_y(1+\beta)\right). \end{aligned}$$

In order to get two stable roots the signs of $H_{n=1}(1)$ and $H_{n=1}(0)$ have to be identical which requires (9). To ensure that there is no further stable root, suppose that $H_{n=1}(0) = -\det(\mathbf{A}) = -\rho/[\beta(1-\mu_y) + \omega\mu_\pi] \in (-1, 0)$, such that there exists at least one stable positive root. Then, there exists exactly two stable roots (indicating stability and uniqueness) if (9) and $H_{n=1}(-1) < 0$, which requires

$$\mu_y(1+\beta) - \omega(1+\rho+\mu_\pi) < 2(\beta+\rho+\beta\rho+1).$$

To establish the second part of the proposition ($n = 0$), we use that the characteristic polynomial of $\mathbf{A}$ changes to

$$H_{n=0}(X) = X^3 + X^2 \frac{(\mu_y - \omega - \beta\rho - \beta + \omega\mu_\pi - 1)}{(1-\mu_y)\beta} + X \frac{(\rho + \beta\rho + \omega\rho + 1)}{(1-\mu_y)\beta} - \frac{\rho}{(1-\mu_y)\beta}$$

where

$$\begin{aligned} H_{n=0}(0) &= -\rho/[(1-\mu_y)\beta], \\ H_{n=0}(1) &= (1-\mu_y)^{-1}\beta^{-1}\left(\omega\rho - \omega + \mu_y + \omega\mu_\pi - \beta\mu_y\right), \\ H_{n=0}(-1) &= (1-\mu_y)^{-1}\beta^{-1}\left(\omega\mu_\pi + \mu_y(1+\beta) - (1+\rho)(\omega + 2(1+\beta))\right). \end{aligned}$$

Suppose that $H_{n=0}(0) = -\det(1) = -\rho/[(1-\mu_y)\beta] \in (-1, 0)$. Then, there exists exactly two stable roots (indicating stability and uniqueness) if (9) and $H_{n=0}(-1) < 0$, which requires

$$\omega\mu_\pi + \mu_y(1+\beta) < (1+\rho)(\omega + 2(1+\beta)).$$

This completes the proof. ■

5.4 Proof of proposition 2

To proof the first part ($n = 1$) of the proposition, the deterministic version of the model with a money demand $\widehat{m}_t = \widehat{x}_t - \gamma \widehat{R}_t$ and money supply (8) with $\rho = 0$ is written as

$$\begin{pmatrix} \widehat{m}_t \\ E_t\widehat{\pi}_{t+1} \\ E_t\widehat{x}_{t+1} \end{pmatrix} = \mathbf{A} \begin{pmatrix} \widehat{m}_{t-1} \\ \widehat{\pi}_t \\ \widehat{x}_t \end{pmatrix}, \text{ where } \mathbf{A} = \begin{pmatrix} 0 & \beta & 0 \\ 1/\gamma & 1 & \sigma \\ 1 & -\mu_\pi & 0 \end{pmatrix}^{-1} \begin{pmatrix} 0 & 1 & -\omega \\ 0 & 0 & \sigma + \gamma^{-1} \\ 1 & -1 & \mu_y \end{pmatrix}$$

The characteristic polynomial of $\mathbf{A}$, which is given by

$$K_{n=1}(X) = X^3 - X^2 \frac{\beta + \sigma\gamma + \gamma\omega + 2\sigma\beta\gamma + \omega\mu_\pi - \beta\mu_y}{\sigma\beta\gamma} - X\frac{\mu_y - \omega - 2\sigma\gamma - \gamma\omega - \beta - \sigma\beta\gamma - 1}{\sigma\beta\gamma} - \frac{\sigma\gamma + 1}{\sigma\beta\gamma},$$

takes the following values at 0, 1 and -1

$$\begin{aligned} K_{n=1}(0) &= -\left(\sigma\gamma + 1\right) / \left(\sigma\beta\gamma\right), \\ K_{n=1}(1) &= \gamma^{-1}\beta^{-1}\sigma^{-1}\left(\omega - \mu_y - \omega\mu_\pi + \beta\mu_y\right), \\ K_{n=1}(-1) &= \gamma^{-1}\beta^{-1}\sigma^{-1}\left(\mu_y\left(1+\beta\right) - \omega\mu_\pi - \omega - 2\left(\gamma\omega + \left(2\sigma\gamma + 1\right)\left(1+\beta\right)\right)\right). \end{aligned}$$

Since $K_{n=1}(0) = -\det(\mathbf{A}) = -\left(\sigma\gamma + 1\right) / \left(\sigma\beta\gamma\right) < -1$, there exists at least one unstable positive root, while there is exactly one stable positive root if (9) is satisfied, such that $K_{n=1}(1) > 0$. Thus, there is exactly one stable root (indicating stability and uniqueness) if (9) and $K_{n=1}(-1) < 0$ which requires

$$\mu_y\left(1+\beta\right) - \omega\mu_\pi < \omega + 2\left(\gamma\omega + \left(2\sigma\gamma + 1\right)\left(1+\beta\right)\right).$$

To establish the second part of the proposition ($n = 0$), we use that the characteristic polynomial of $\mathbf{A}$ changes to

$$K_{n=0}(X) = X^3 - X^2 \frac{\beta + \sigma\gamma + \gamma\omega + 2\sigma\beta\gamma - \beta\mu_y}{\sigma\beta\gamma} - X\frac{\mu_y - \omega - 2\sigma\gamma - \gamma\omega - \beta - \sigma\beta\gamma + \omega\mu_\pi - 1}{\sigma\beta\gamma} - \frac{\sigma\gamma + 1}{\sigma\beta\gamma}.$$

Since $K_{n=0}(0) = K_{n=1}(0) < -1$, there exists at least one unstable positive root, while there is exactly one stable positive root if (9) is satisfied, such that $K_{n=0}(1) = K_{n=0}(0) > 0$. Thus, there is exactly one stable root (indicating stability and uniqueness) if (9) and $K_{n=0}(-1) = [\omega\mu_\pi + \mu_y\left(1+\beta\right) - \omega - 2\left(\left(1 + 2\sigma\gamma\right)\left(1+\beta\right) + \gamma\omega\right)] / \left(\sigma\beta\gamma\right) < 0$ which requires

$$\omega\mu_\pi + \mu_y\left(1+\beta\right) < \omega + 2\left(\left(1 + 2\sigma\gamma\right)\left(1+\beta\right) + \gamma\omega\right).$$

This completes the proof. ■

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