Taylor-Based Monetary Policy Rules: Are They Forward-Looking, Data Congruent, and Asset Price Responsive?

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TAYLOR-BASED MONETARY POLICY RULES: ARE THEY FORWARD-LOOKING, DATA CONGRUENT, AND ASSET PRICE RESPONSIVE?

by

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Rajeev Sooreea
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INTRODUCTION

Discussions about monetary policy rules since Taylor's (1993) pioneering work have more or less revolved around what has generally been known as the Taylor rule. The Taylor rule models the Fed Funds rate as a function of the deviation of inflation from a target rate and the deviation of real Gross Domestic Product (GDP) from potential real GDP (that is, its long-run sustainable trend). The rule assumes that policymakers seek to stabilize output and prices about paths that are thought to be optimal and they do so by changing the interest rate target, the nominal Fed Funds rate. If inflation is above the target, the Fed responds by raising rates to prevent inflationary pressures in the economy, and if inflation is below target it eases policy. The output gap is also a measure of inflationary pressures in essence. If real GDP is above its potential, the Fed tightens policy and vice-versa.

Taylor (1993) argues that this simple rule is a good representation of how the Fed sets its policy instrument. However, critics have shown that the so-called Taylor rule misses out on the inertial behavior of the Fed and this has led to an enormous literature on optimal policy rules as opposed to simple policy rules (Giannoni and Woodford, 2001). Yet, among the class of optimal policy rules, there is a division about how these rules are specified and what characteristics are embedded in them. Some argue that Taylor-type policy rules are forward-looking while others maintain
that they are backward-looking. Such debates invariably mean that a huge class of Taylor rules has emerged over time in the search for the one rule that most appropriately describes the Fed Funds rate behavior. Moreover, concerns about asset prices have altogether rendered policy rules more complex. This study presents three essays to address three key challenges that face monetary policymakers today.

The first essay examines whether Taylor-type monetary policy rules are forward-looking. Most of the studies in the literature use statistical break tests to analyze the parameter stability of Taylor rules. However, parameter stability is only one aspect of forward-lookingness; another is the structural invariance of the parameters. This study attempts to fill in this gap in the literature by exploring the superexogeneity test of Engle and Hendry (1993) and invoking the Lucas (1976) critique. The hypothesis that we want to empirically test is that inflation is superexogenous for the parameters of the Taylor rule. While weak exogeneity is sufficient for forecasting analysis, superexogeneity is required for policy analysis. The methodology adopted is that if the parameters of the Taylor-type rule change when the mechanism generating inflation changes, that is the Lucas critique applies, then inflation is not superexogenous for the parameters of the Taylor rule. The rationale of this is that we want to investigate whether monetary policymakers can change the process that determines inflation without affecting the process that determines the Fed Funds rate. To account for the structural break in the marginal model (Phillips curve) this study uses a heteroskedastic variance model that allows for discrete regime shifts in the volatility of inflation. The a priori belief is that if the Lucas critique holds, then
structural breaks in the inflation process should cause the parameters of the Taylor rule to change thus resulting in a forward-looking behavior of the Taylor rule.

In the second essay, we focus on the issue of whether Taylor-based monetary policy rules are encompassing which is one aspect of data congruency. That is, we want to investigate which policy rule among existing rival ones most appropriately describes the Fed Funds rate data generating process. Since Taylor's (1993) rule, several rival models of the Fed Funds rate have emerged in an attempt to explain the Fed Funds rate behavior. However, although there seems to be less disagreement on the general functional form of Taylor-type rules, there is no consensus on rule specifics. Which measures of inflation and output gaps to use in Taylor-type rules have not been given adequate formal treatment and the use of the wrong measures can result in policy mistakes. The different measures of inflation and output gaps essentially differ based on the underlying inflation and potential output variables used. To this effect, the question of which inflation variable policymakers should attempt to stabilize may not be as simple as it seems because the level and direction of inflation movements differ for different measures of inflation and justifying a given choice measure may prove difficult. Similarly, which potential output measure to use may not be a trivial issue. This study attempts to solve this debate by focusing on a class of Taylor-type rules that are non-nested in the sense that they cannot be expressed as a restricted version of one another; that is, in essence they are rivals to one another. To do the analysis, it employs the encompassing principle of Hendry (1985), the multivariate non-nested P test of Davidson and MacKinnon (1981) and the serial
correlation extension of the non-nested P test proposed by McAleer, Pesaran and Bera (1990). Five inflation and four output gap measures are used and 116 non-nested P tests are performed to examine which interest rate model encompasses competing alternatives. The study unambiguously comes up with one single measure of inflation and output gap that best describe the Fed Funds rate data generating process.

The third essay augments the model from the second essay to investigate one issue that has been of great concern to monetary policymakers since the stock market rally of the early 1980s, namely, whether policy rules are asset price responsive. The importance of this issue is that if asset prices contain vital information about the economy then the question is: Does the Fed react to asset prices while designing monetary policy? In particular, this study examines if it does, then to which component does it respond? To address such issues in the literature, most studies have simply concentrated on a direct measure of asset prices. However, this study uses a non-linear model of intrinsic bubbles to decompose stock prices into market fundamentals and stock price bubbles. Moreover, it employs an Exponential Generalized Autoregressive Conditional Heteroskedastic (E-GARCH) model to gauge volatility clustering and leverage effects inherent in equity returns. These constructed measures of asset price bubbles, market fundamentals and uncertainty-creating volatility are then used as additional indicators in the Fed's reaction function. To substantiate the results, it also uses a direct measure of productivity to proxy for market fundamentals.
The study of Taylor rules is not novel. However, there are five contributions of this study that can be considered new:

1. No study, to the extent of our knowledge, has investigated the forward-lookingness of Taylor-based monetary policy rules using formal superexogeneity tests and focusing on structural invariance considerations.

2. This study models the structural break in the volatility of inflation using a heteroskedastic variance model that allows for discrete regime shifts.

3. The analysis of the data congruency of Taylor rules using non-nested tests and the encompassing principle is novel.

4. This study identifies the one measure of inflation and output gap that is most consistent with the Fed Funds rate behavior and also shows that other rival models fail to appropriately characterize the interest rate data generating process.

5. This study analyzes which specific components of the stock market the Fed responds to if it does respond. Estimating and incorporating the conditional variance from an E-GARCH model, and a measure of intrinsic bubbles and stock market fundamentals into the Taylor rule is a new contribution as this helps in determining whether there is any response of the Fed to stock market uncertainty, irrational exuberance and productivity growth respectively.
PART II

ARE TAYLOR-BASED MONETARY POLICY RULES FORWARD-LOOKING?
AN INVESTIGATION USING SUPEREXOGENEITY TESTS

Introduction

One of the key challenges that face U.S. monetary policymakers is whether monetary policy rules of the Taylor (1993) type are forward-looking or backward-looking. The basic structure of the Taylor-type policy rule models the short interest rate (the Federal Funds rate) as a function of the inflation gap, the output gap and an interest rate smoothing component. The general notion in the literature is that a variable is forward-looking if it depends on expectations of future variables. Svensson (2003) notes that, formally, a variable is forward-looking if it depends on expectations of future variables and has endogenous one-period-ahead forecast errors. Conversely, a variable is backward-looking if it depends on its past values. An extension of this idea to monetary policy rules would then suggest that interest rate rules are forward-looking if they contain some measures of expected inflation and/or output gap, and backward-looking if the indicator variables enter as lagged representations. However, this paper argues that a more formal test is needed before we can conclude whether a rule feeds forward or backward.

The type of tests that this paper deals with invokes the Lucas (1976) critique and the superexogeneity test of Engle and Hendry (1993). According to the Lucas
critique, changes in policy affect the behavior of rational agents and such behavioral changes can invalidate the model relationships estimated under the previous policy regime. In other words, shifts in economic policy change how policy affects the economy because agents in the economy are forward- rather than backward-looking and adapt their expectations and behavior to the new policy stance (Linde, 2001). Empirical studies of monetary policy rules suggest that the behavior of the U.S. monetary policymakers changed during the past few decades (Judd and Rudebusch (1998), Taylor (1999), Clarida, Gali and Gertler (1999), and Estrella and Fuhrer (2000)). These studies found that the parameters of the rules are not stable. This evidence would suggest that the Lucas critique holds. However, at the same time, models with lagged representations of the economy such as Vector Autoregressions (VARs) often did not exhibit any structural instability (Bernanke and Mihov (1998), Estrella and Fuhrer (2000), Leeper and Zha (2001)). Recognizing that these two sets of empirical results appear to contradict the Lucas critique, Rudebusch (2003) attempts to reconcile this discrepancy by showing that the apparent policy invariance of reduced form models like the VARs is consistent with the magnitude of historical policy shifts and the relative insensitivity of the reduced forms of forward-looking models.

However, the issue of forward-lookingness still remains unsettled. Studies that investigate the forward- or backward-lookingness of reaction functions derive their conclusions based solely on statistical break or stability tests of the Chow type, Lagrange multiplier (LM) test of Andrews and Fair (1988), predictive test (TS) of
Ghysels and Hall (1990), or multiple unknown breakpoints test of Bai (1999). Using these kinds of stability tests and simulation techniques, Estrella and Fuhrer (2003) and Rudebusch (2003) find that the magnitude of the Lucas effect – the reaction of agents’ behavioral equations to structural changes in policy – has not been very large in practice. To help solve the divergence of views on the forward- versus backward-lookingness of policy rules this paper proposes a methodology using superexogeneity tests. The methodology is to test whether the target variable, say, inflation, is superexogenous to the parameters of the Taylor-type rule. If, when the mechanism generating inflation changes, the parameters of the Taylor-type rule change – that is the Lucas critique applies – then inflation is not superexogenous for the parameters of the Taylor rule. In this case where superexogeneity fails, the rule is forward-looking. The implication of this is that the Fed cannot change the process that determines inflation without affecting the process that determines the Federal Funds rate.

Interestingly, the results show that the null that inflation is superexogenous to the parameters of the Taylor rule cannot be rejected over the 1983Q1 to 2002Q2 period. This suggests that there is no sufficient evidence to reject the claim the Taylor rules are not forward-looking.

The Superexogeneity Test Methodology

In the literature, the practical application of the superexogeneity tests is due to Engle and Hendry (1993). Other studies such as Caporale (1996), Darrat et al (1998) and Perez (2000) are simplified versions of it. Engle and Hendry (1993) describe a
testing methodology based on the superexogeneity concept of Engle, Hendry and Richard (1983). This requires the specification of the conditional and marginal distributions of the variables of interest. In terms of our Taylor-type monetary policy rule the immediate variables of interest are the Fed Funds rate and the inflation gap. The inflation gap, $\pi_t$, is measured as the deviation of inflation from a 2 percent target level. Inflation is calculated following the standard procedure in the Taylor rule literature, that is, the percentage change in the Gross Domestic Product (GDP) price deflator over the previous four quarters. Then the joint distribution of the Federal Funds rate, $r_t$, and the inflation gap, $\pi_t$, can be written as:

$\begin{align*}
D_j(r_t, \pi_t | F_t; \lambda) &= D_C(r_t | \pi_t, F_t; \lambda_{1t}) D_M(\pi_t | F_t; \lambda_{2t}) \\
\end{align*}$

where $D_j$, $D_C$, and $D_M$ denote the joint density, the conditional density of $r_t$ given $\pi_t$, and the marginal density of $\pi_t$, respectively, and $\lambda_t$, $\lambda_{1t}$, and $\lambda_{2t}$, the corresponding parameters. $F_t$ represents the field of information including past values of $r_t$ and $\pi_t$ as well as current and past values of other valid conditioning variables.

By Engle and Hendry (1993), $\pi_t$ would be defined as being superexogenous for $\theta$ (a set of parameters of interest) if $\pi_t$ is weakly exogenous for $\theta$ and $\lambda_1$ is invariant to changes in $\lambda_2$ (i.e., changes in $\lambda_2$ do not imply changes in $\lambda_1$). $\pi_t$ is defined as weakly exogenous for $\theta$ if $\theta$ is a function of the parameters $\lambda_{1t}$ alone, and $\lambda_{1t}$ and $\lambda_{2t}$ are variation-free (that is, over periods of constant $\lambda_{2t}$ there is no information in $\lambda_2$ that would help estimating $\lambda_1$ (Engle, Hendry and Richard (1983)). The important
distinction between weak and superexogeneity is that weak exogeneity is sufficient for the conditional model to be used in forecasting analysis, whereas policy analysis requires superexogeneity. Pearl (2000) notes that superexogeneity (or what she calls exogeneity) is a notion that captures economists’ interest in the structural invariance of certain relationships under policy intervention.

The conditional distribution of the Fed Funds rate is in fact an augmented Taylor rule which can be specified as follows:

\[ r_t = \pi_t \beta + z_t' \gamma + u_t \]

where \( z_t \) represents the vector of all other conditioning variables like the lagged Fed Funds rate, \( r_{t-1} \), and the output gap, \( y_t \). The output gap is measured as the percentage deviation of real Gross Domestic Product from real potential GDP as calculated by the Congressional Budget Office. \( \beta \) and \( \gamma \) are the parameters of the model. This augmented Taylor rule is quite standard in the literature (see Taylor (1999), Kozicki (1999), Woodford (1994, 1999, 2001)). \( u_t \) is the error term that follows a stationary AR(1) process:

\[ u_t = \rho_0 u_{t-1} + \nu_t, \quad \nu_t \sim NID(0, \sigma^2), \quad |\rho_0| < 1. \]

To test the null hypothesis that the inflation gap \( \pi_t \) is superexogenous for \( \beta \), we first need to specify the marginal distribution of \( \pi_t \). Suppose there is a set of instruments \( Z_{it} \), including \( z_t \), which describes the mean of \( \pi_t \) through:

\[ \pi_t = Z_{it}' \psi + \eta_t \]
The construction of $Z_t$ is assumed to allow for and define regime shifts in the data generating process of $\pi_t$. This specification gives wide scope to specifying changes in policy regime, expectations formation, or states of nature. Essentially equation (4) represents a Phillips curve with the vector $Z_t$ containing the inflation and output gaps. $\psi$ represents the parameters of the marginal distribution and $\eta_t$ denotes the error term.

Following Engle and Hendry (1993), the superexogeneity test can be formulated based on the following regression:

\[(5) \quad r_t = \pi_t + \gamma + (\delta_0 - \beta_0)\hat{\eta}_t + \delta_1\sigma_1^2\hat{\eta}_t + \beta_2\sigma_1^2 + \beta_3\sigma_1^2 + \varepsilon_t\]

where $\sigma_i^2$ is the conditional variance of $\eta_i$. This specification allows for heteroskedasticity in the error term of (4). Then to test the null hypothesis that the inflation gap, $\pi_t$, is superexogenous for $\beta_0$, we perform the following joint test:

\[(6) \quad H_0 : \phi_1 = \delta_0 = \beta_1 = \beta_2 = \beta_3 = 0\]

where $\phi_1 = \delta_0 - \beta_0$.

**Estimation Results**

This section presents the estimated Phillips curve (marginal model) and the results of the superexogeneity test.

**Phillips Curve Marginal Equation**

Different studies in the literature provide different specifications of the
Phillips curve. Some are what is referred to as forward-looking (Roberts (1995), McCallum and Nelson (1999), Clarida, Gali and Gertler (1999), and Svensson (2003)), and some with inflation inertia (Bomfim and Diebold (1997) and Razzak (2002)). However, some studies such as Fuhrer (1997), Fair (1993), Chadha et al (1992), Roberts (1995, 2001), Laxton et al (1998), Rudebusch and Svensson (1999), Rudebusch (2001), and Estrella and Fuhrer (2003) argue that there is some evidence that expectations in Phillips curve are backward-looking. Our estimation results seem to support the specification of Phillips curve that has a lagged representation of inflation and output gap:

\[
\pi_t = 1.253\pi_{t-1} - 0.277\pi_{t-2} + 0.030y_{t-1} + \eta_t,
\]

\( R^2 = 0.93, \ LM = 0.27 \ [p\text{-value}=0.87] \)

where the numbers in parentheses represent t-statistics, \( R^2 \) is the coefficient of determination and \( LM \) is the Lagrange-Multiplier test for serial correlation. This result is consistent with the findings in the literature: there is a great deal of inertia in the inflation process while the output gap is mildly important. While there is no serial correlation in the residuals, we model below the possibility of heteroskedasticity.

Since the construction of \( Z_t \) in (4) is assumed to allow for and define regime shifts in the data generating process of \( \pi_t \), we perform a series of Chow breakpoint and dummy variable tests for specific dates where we believe \textit{a priori} (based on underlying economic reasons) that there could be a certain structural change in the inflation process. For instance, Chairman Greenspan is believed to have been
successful in controlling inflation. So, we carried out a Chow breakpoint test for 1987Q2 to allow for any regime shift that could possibly exist when Greenspan was appointed. Such a point was also identified by Estrella and Fuhrer (2003). However, the test turns out to be insignificant with an F statistic of 1.12 [p-value=0.35]. Similar tests for the 1987 stock market crash, the 1990 S&L and Persian Gulf crises, the 1994 Mexican Peso crisis, the 1997 Pacific Rim crisis and the 1998 Russian Default crisis fail to identify any structural break. However, the Chow breakpoint test captured the 2001 recession, the F statistic being 4.48 [p-value=0.01]. In fact, in 2001, inflation was higher than in the surrounding years. To account for the period of high productivity growth in the mid to late 1990s, where inflation declined substantially, dummy variables were included; however, they turned out to be insignificant. Overall, Chow breakpoint and dummy variable tests do not seem to suggest that there is a structural break in the inflation process.

However, a closer look at the inflation data in Figure 1 suggests that the volatility of inflation has indeed changed over the sample period. After the 1991 recession, it appears that there has been less variability in inflation (shaded area). Although the residuals (measured on the left scale) from the estimated Phillips curve are within the 2 standard error bounds (dotted straight lines) except for just a couple of years, they tend to be more erratic before 1990-1991 than afterwards. A check on the recursive residuals in the spirit of Hendry (1988) was also done and it also suggests the same.
Figure 1. Inflation Gap: Actual, Fitted and Residuals

To model for the different regimes of inflation volatility, we allow the variance of the error term $\eta_i$ in (4) to follow a discrete heteroskedastic process as follows:

\begin{equation}
V(\eta_i) = \alpha_0 + \alpha_1 d_i,
\end{equation}

where $d_i$ is a dummy variable that equals 1 for 1991Q1 onwards and 0 prior to 1991.

Using the estimates $\hat{\alpha}_0$ and $\hat{\alpha}_1$ we then construct the following conditional variance series for $\eta_i$:

\begin{equation}
\hat{\sigma}_i^2 = 0.068 - 0.035 d_i,
\end{equation}

(0.01) (0.01)
The numbers in parentheses represent standard errors. The coefficient of the dummy variable, being significant and negative and almost half of the intercept term, implies that the variability in the inflation process almost halved for the post-1991 period. Indeed, the 1990s were a period of sustained productivity growth, stock market optimism and confidence, and a hawkish Fed whose primary objective was to maintain price stability. Hence, a reduction in inflation uncertainty seems to be a verified empirical fact.

Conditional Taylor Rule and Superexogeneity Tests

Using $\hat{\sigma}_t^2$ and $\hat{\pi}_t$, we construct $\hat{\pi}_t \hat{\sigma}_t^2$ and estimate the model given in (5).

The results are as follows:

$$
r_t = 2.199 + 0.600\pi_t + 0.346y_t + 0.426\sigma_{t-1} + 0.897\hat{\pi}_t - 14.484\hat{\sigma}_t^2 \hat{\pi}_t \\
(2.12) \quad (1.06) \quad (3.46) \quad (3.41) \quad (1.47) \quad (-1.21)
$$

(9)

$$
-0.092\hat{\sigma}^2_t + 17.243\hat{\sigma}_t^2 + 5.296\hat{\pi}_t \hat{\sigma}_t^2 \\
(-0.67) \quad (0.74) \quad (0.44)
$$

Numbers in parentheses represent t-statistics. Several results fall out from (9). First, as Engle and Hendry (1993) points out, the weak exogeneity of $\pi_t$ for $\beta_0$ in (5) entails a zero effect from $\hat{\pi}_t$. The insignificance of the coefficient of $\hat{\pi}_t$ as shown in (9) implies that the inflation gap is indeed weakly exogenous for $\beta_0$. Second, constancy of $\hat{\sigma}_t$ entails $\hat{\sigma}_t = 0$. Indeed, the result in (9) indicates that the coefficient of $\hat{\sigma}_t^2 \hat{\pi}_t$ is not significantly different from zero (t-statistic being -1.21). Third, the
invariance of $\beta$ in (2) entails that $\beta_1 = \beta_2 = \beta_3 = 0$. A joint test produces an F-statistic of 1.93 [p-value=0.133] suggesting that $\beta$ is invariant. Finally, the joint test that $H_0 : \phi = \delta = \beta_1 = \beta_2 = \beta_3 = 0$ produces an F-statistic of 1.53 [p-value=0.192], indicating that we cannot reject the null that the inflation gap is superexogenous for the parameters of the Taylor rule. This means that there is not sufficient evidence to reject the hypothesis that the Lucas critique fails and the claim that Taylor rules are not forward-looking. Estrella and Fuhrer (2003) showed, through a set of stability tests, that backward-looking reaction functions are more stable and do not undergo parameter instability when policy changes.

Conclusion

This study has examined an important policy question, namely whether Taylor-based monetary policy rules are forward-looking. Studies that investigate the forward- or backward-lookingness of reaction functions derive their conclusions based solely on statistical break tests. This study, on the other hand, proposes a simple test of forward-lookingness in policy rules by appealing to the Lucas critique and the superexogeneity test of Engle and Hendry (1993). The methodology adopted is that if the parameters of the Taylor-type rule change when the mechanism generating inflation changes, that is the Lucas critique applies, then inflation is not superexogenous for the parameters of the Taylor rule. In this case where superexogeneity fails, the rule is forward-looking.

To conduct the analysis this study first estimates a Phillips curve of the form
that is well established in the literature. Then it carries out a set of structural break
tests to identify possible regime shifts. The structural break in the inflation process
was best captured by a discrete heteroskedastic variance model which explains the
volatility of inflation. However, although the results indicate that the volatility of
inflation reduced by almost 50 percent over the second half of the sample period, we
fail to reject the null that inflation is superexogenous to the parameters of the Taylor
rule. There is also no sufficient evidence to reject weak exogeneity, parameter
constancy and structural invariance. Overall, the results suggest that we cannot reject
the claim that Taylor-based rules are not forward-looking. Because of the lack of
power of superexogeneity tests, the next chapter uses a more direct methodology to
identify the measures of inflation and output gap that most appropriately characterize
the interest rate data generating process.
PART III

ARE TAYLOR-BASED MONETARY POLICY RULES ENCOMPASSING?
A NON-NESTED TESTS APPROACH

Introduction

Taylor’s (1993) study on monetary policy rules has been the most influential pioneer work on the determinants of the Federal Funds rate behavior. In response to Taylor, a huge amount of theoretical and empirical literature on policy rules and Fed reaction functions has emerged with the objective of building models that correctly explain the Fed Funds rate behavior. Rule specifications have varied in general functional form as well as in specifics to produce a class of rules that could be best labeled as Taylor-type rules. Although there seems to be less disagreement on the general functional form of Taylor-type rules, there is no consensus on rule specifics. Which measures of inflation and output gaps to use in Taylor-type rules have not been given adequate formal thoughts.

The different measures of inflation and output gaps essentially differ based on the underlying inflation and potential output variables used. To this effect, the question of which inflation variable policymakers should attempt to stabilize may not be as simple as it seems because the level and direction of inflation movements differ for different measures of inflation and justifying a given choice measure may prove difficult. Similarly, which potential output measure to use may not be a trivial issue.
Kozicki (1999) argues that to be useful to policymakers, rule recommendations should be robust to minor variations in the rule specification. She explains that if, for instance, recommendations differ considerably depending on whether price inflation is measured using the core consumer price index or the GDP deflator, then the rule may not be very useful. Similarly, Kuttner (1992) comments that uncertainty in estimates of the output gap may mean that situations requiring policy action may not be recognizable until later on.

Different studies have used different measures of inflation and output gaps in trying to explain the Fed Funds behavior. In his work, Taylor (1993) uses the GDP deflator measure of inflation. This measure has been widely used in the literature on Taylor rules (see for instance, Clarida, Gali and Gertler (2000), Woodford (2001), Rigobon and Sack (2001)). Clarida, Gali and Gertler (2000) also use the Consumer Price Index (CPI) inflation measure, and so do Filardo (2000) and Bernanke and Gertler (2001). Some studies such as Filardo (2000) use the core CPI while some others like Clarida, Gali and Gertler (2000) use the commodity price inflation. Goodhart (2000) has recommended that central banks should replace conventional inflation measures such as the CPI or personal consumption expenditure price index with a broader measure that includes housing and stock market prices in order to improve macroeconomic performance. To account for the forward-looking behavior of rules, Kozicki (1999) uses the University of Michigan expected inflation measure and the Philadelphia Fed expected inflation measure.
As far as the output gap is concerned, some studies use the Congressional Budget Office (CBO) measure. These include Clarida, Gali and Gertler (2000), Rigobon and Sack (2001) amongst others. Taylor (1993) himself used an output gap based on a linear time trend real GDP. More recently, Taylor (1999) uses the Hodrick-Prescott filter trend measure to calculate the output gap. De Masi (1997) from the International Monetary Fund (IMF) provides a measure of potential output based on a segmented trend approach and Kozicki (1999) uses this IMF measure together with other measures to examine policy rules. Woodford (2001) argues that real unit labor cost is a much better measure of the true output gap for purposes of explaining inflation variation, but he also points out that such a measure would have practical implementation problems in a Taylor rule framework.

Employing five commonly used measures of inflation and four commonly used measures of the output gap, we have plotted the range of the 20 rule recommendations (the Fed’s ex-ante Fed Funds rate) in Figure 2 during the 1983Q1 to 2002Q2 period. The dashed lines reflect the range of rule recommendations based on recommendations calculated for each of the five measures of inflation and each of the four measures of output gap. In each quarter, the maximum of the range corresponds to the maximum of the 20 rule recommendations, and the minimum of the range corresponds to the minimum of the 20 rule recommendations. The average range is 1.64 percentage points. However, the range fluctuates considerably, reaching its narrowest at 0.65 percentage point in 1997Q1 and reaching its widest at 4.19 percentage points in 1983Q1. There are also periods, for instance the early 1980s, mid-
1990s and 2001 onwards, where the actual Fed Funds rate value has been totally outside the range of rule recommendations.

Figure 2. The Range of Taylor-Type Rule Recommendations for the Fed Funds Rate

Overall, the range shows how erratic the rule recommendations are with respect to the actual Fed Funds rate behavior. Indeed, in the literature there has been no basis to choose the correct inflation and output gap measures that enter the policy rule.

In this paper we conduct a series of formal tests to pin down the measures of inflation and output gaps that are congruent with the Fed Funds rate data generating process over the 1983Q1 to 2002Q2 period. We focus on a class of non-nested Taylor-type rules and employ the encompassing principle to show that the measures
of inflation and output gap that are consistent with the Fed Funds rate behavior are the Philadelphia Fed measure of expected inflation as calculated by the Survey of Professional Forecasters and the Congressional Budget Office (CBO) measure of output gap. Taylor rules based on these measures of inflation and output gaps alone are encompassing.

Taylor Rules and the Non-Nested Test Methodology

Since the aim of this study is concerned with the specifics of the Taylor-type rule — and not its general functional form — we therefore start by assuming a standard augmented Taylor rule of the form that is commonly accepted in the literature. Such a generic widely accepted monetary policy Taylor-type rule can be described as

\begin{equation}
    r_t = \beta_0 r_{t-1} + \beta_1 + \beta_2 \pi_t + \beta_3 y_t + u_t
\end{equation}

where \( r_t \) represents the nominal Fed Funds rate at time \( t \), \( \pi \) represents the inflation gap measured as the deviation of inflation from a 2 percent target level, \( y \) is the output gap measured as the percentage deviation of real GDP from potential real GDP, and \( u \) is the error term that follows a stationary AR(1) process:

\begin{equation}
    u_t = \rho_0 u_{t-1} + \epsilon_t, \quad \epsilon_t \sim NID(0, \sigma^2), |\rho_0| < 1.
\end{equation}

Equation (10) is an augmented Taylor rule because it comprises the lagged interest rate. Taylor's (1993) rule omits the interest rate smoothing parameter. Rudebusch (2002) argues that the lagged interest rate is not a fundamental component of the U.S. policy rule, and that its significance arises from the omission of serially correlated variables from the policy rule. By contrast, English, Nelson and Sack
(2002) find that while serially correlated omitted variables may be present, the lagged interest rate enters the policy rule in its own right and plays an important role in describing the behavior of the Fed Funds rate. In the literature, many analysts have noted that the Fed has a tendency to smooth movements of the Funds rate (Goodfriend (1991), Orphanides (1997), and Clarida, Gali and Gertler (1998)).

The constant term $\beta_1$ subsumes the equilibrium real interest rate and the inflation target and it provides a benchmark recommendation for the nominal Fed Funds rate. The inflation gap adjustment factor $\beta_2$ recommends raising the Fed Funds rate above the benchmark if inflation is above the target for inflation and lowering the Fed Funds rate below the benchmark if inflation is below the target. Some analysts argue that the output gap adjustment factor $\beta_3$, brings a forward-looking, or preemptive, motive to policy recommendations. In this view, a positive output gap signals likely future increases in inflation and therefore an increase in the Fed Funds rate.

The focus of this study is to discover which are the correct variables for $\pi$ and $y$ that best describe actual $r_t$ over the sample period 1983Q1 to 2002Q2 for the U.S. economy. We use data starting from 1983Q1 for a couple of reasons. First, because we are interested in understanding the behavior of the Fed Funds rate and not some other monetary targets, it is plausible to avoid the 1979-82 period where the Fed targeted the non-borrowed reserves. Moreover, this has become a standard practice in the literature. Secondly, we want to see how our results compare with those of previous studies, including Kozicki (1999). We use five different inflation measures.
and four different output gap measures and this implies that the 20 rival models are non-nested.

The five measures of inflation are CPI, Core CPI, Taylor’s GDP price inflation, University of Michigan expected inflation, and Philadelphia Fed expected inflation. CPI inflation is measured as the percent change in the consumer price index over the previous four quarters. Core CPI inflation is measured as the percent change in the consumer price index excluding food and energy over the previous four quarters. Taylor’s GDP price inflation, which the Taylor rule uses, is calculated as the percent change in the GDP price deflator over the previous four quarters. The University of Michigan expected inflation, calculated by the Survey of Consumers as the median expected price change over the next 12 months, is obtainable from the St. Louis Fed database and then converted to quarterly frequency. The Philadelphia Fed measure of inflation is the one-year ahead average inflation forecast for chain-weighted GDP price index as reported by the Survey of Professional Forecasters.

These five measures comprise of both backward-looking as well as forward-looking measures. CPI, core CPI and Taylor’s GDP price inflation are backward-looking in that they describe inflation over a time period that has already past. On the other hand, the University of Michigan expected inflation and the Philadelphia Fed expected inflation are forward-looking in that they describe inflation as it is expected to be over a future time period. The huge debate about whether Taylor rules are or should be backward-looking or forward-looking is a rationale for including both types of inflation measures in the analysis. Svensson (2003), Svensson and Woodford
(2003), Hansen and Sargent (2003), Batini and Haldane (1999), Carlstrom and Fuerst (2000), Woodford (2000), Clarida, Gali, and Gertler (1998), and Orphanides (1997) provide a good discussion on backward-looking and forward-looking rules. Using these inflation measures, the inflation gaps are then constructed as the deviations of these measures of inflation from a 2 percent target level.

The four measures of output gap differ according to the estimates of the potential output (that is, its long-run sustainable trend). Potential real GDP is a theoretical construct and there are various approaches to estimate it. We use four measures of potential real GDP: Congressional Budget Office (CBO), Hodrick-Prescott filter trend, Taylor’s linear time trend, and International Monetary Fund (IMF). The CBO potential real GDP was obtainable from the CBO. It is calculated using a neoclassical production function (see Arnold, 1995). The Hodrick-Prescott filter trend is estimated with a smoothing parameter of 1600 given the quarterly nature of our data. Taylor’s measure of potential GDP is calculated as the fitted values from a regression of the natural logarithm of real GDP on a constant and time trend. The IMF potential output series was interpolated from an annual potential output series constructed by the IMF using a segmented trend approach. This approach assumes that the rate of growth of potential output changes at specific structural points, but is constant between these points (see De Masi, 1997).

The output gap is constructed as the difference between real GDP and potential real GDP expressed as a percentage of potential real GDP. Different measures of the output gap are considered because policymakers often recognize that
there are difficulties in assessing the output gap, and assuming one measure of output gap over another can mislead policy that attempts to judge inflationary risks in the economy. A case in point is Governor Gramlich’s (1998) comment: “For the Fed to lean against the wind of output gaps, it has to know what the output gaps are, and that too can become quite tricky as unemployment approaches its desired level.”

Identifying which of these measures of inflation and output gaps enter the Taylor-type monetary policy rules eventually boils down to: which Fed Funds rate model is data congruent? That is, which model is the appropriate characterization of the Fed Funds rate data generating process? The problem becomes more complex when rival models are non-nested. Two models are said to be non-nested if either model cannot be expressed as a restricted version of the other. In this study, we use the idea of the encompassing principle of Mizon and Richard (1986) to pin down a data congruent model for the Fed Funds rate when non-nested competing alternatives exist. We use a Taylor-type monetary policy rule setting as the underlying model framework.

One complication of Taylor-type rules is that they tend to be non-linear because of lagged dependent variables (usually from the interest-rate smoothing behavior) and the possible existence of serial correlation in the disturbance term. Testing non-nested nonlinear models can be traced back to Pesaran and Deaton (1978), based on the earlier work of Cox (1961, 1962) and Pesaran (1974). Pesaran (1974) derives a test of a linear regression model against a non-nested linear alternative when the regressors of both models are non-stochastic and the errors
follow a stationary first-order autoregressive (AR(1)) process. The approach relies on Cox's (1961, 1962) method for testing separate families of hypotheses. Davidson and MacKinnon (1981, 1993) clarify the use of different tests depending on whether the null (the maintained model) is linear or nonlinear. They recommend using the J test when the null is linear. However, McAleer, Pesaran and Bera (1990) argue that a direct extension of the J test procedure to models with serial correlation is not valid. In the case of a non-linear null with serial correlation, the P test of Davidson and MacKinnon (1981) is recommended. The Cox test of Pesaran and Deaton (1978) and the P test are asymptotically equivalent under the null. In our study, we use the multivariate version of the P test of Davidson and MacKinnon (1981). In a Taylor-type rule setting, the test is constructed as follows. First, we substitute (11) into (10) and rearrange terms to get

\[ r_t = \beta_0 r_{t-1} + (r_{t-1} - \rho_0 r_{t-2}) \beta_0 + (1 - \rho_0) \beta_1 + (\pi_t - \rho_0 \pi_{t-1}) \beta_2 + (y_t - \rho_0 y_{t-1}) \beta_3 + \epsilon_t. \]

This equation is nonlinear and the J test is not valid. To construct the P test, Davidson and MacKinnon (1981) and McAleer, Pesaran and Bera (1990) recommend linearizing the J test regression and calculating the following partial derivatives:

\[ \frac{\partial r}{\partial \beta'} = (r_{t-1} - \rho_0 r_{t-2}, 1 - \rho_0, \pi_t - \rho_0 \pi_{t-1}, y_t - \rho_0 y_{t-1}) \]

\[ \frac{\partial r}{\partial \beta_0} = r_{t-1} - \beta_0 r_{t-2} - \beta_1 - \beta_2 \pi_{t-1} - \beta_3 y_{t-1} \]

The P test is then the t-test of \( \lambda = 0 \) in the linear regression.
\[ r_t - \hat{r}_t = \alpha_0 (1 - \hat{\rho}_0) + \alpha_3 (\pi_t - \hat{\rho}_0 \pi_{t-1}) + \alpha_2 (y_t - \hat{\rho}_0 y_{t-1}) + \alpha_3 (r_{t-1} - \hat{\rho}_0 r_{t-2}) \]
\[ + \alpha_3 (r_{t-1} - \hat{\beta}_3 r_{t-2} - \hat{\beta}_1 - \hat{\beta}_3 \pi_{t-1} - \hat{\beta}_2 y_{t-1}) + \lambda (\hat{r}_t - \hat{\mu}) + \nu_t \]

where \( \hat{r}_t \) and \( \hat{r}_t^* \) are the predictions of the Fed Funds rate under the null and the alternative non-nested model respectively and \( \nu_t \) is gaussian white noise. In essence, the difference in (15) represents the prediction errors under the two competing hypotheses. To get the parameter estimates in (12) the maximum likelihood estimation technique is used, whereas least squares suffice to estimate equation (15).

Estimated Reaction Functions and Non-Nested P Test Results

In this section we report the results of the non-nested P test as given by equation (15). Before conducting the non-nested tests, however, we also report the results of the estimated reaction functions in Table 1. The results appear to be consistent with the literature. The general pattern is that the policy rule tends to give more weight to inflation than to the output gap. This is particularly true when inflation is measured as GDP price inflation or expected inflation. There is also a substantial degree of policy inertia as evidenced by the interest rate smoothing parameter. Such results are standard in the literature. When core CPI measure of inflation is used, it sometimes appear not to be significant in the policy rule, and also the fit is relatively not good as the standard error of the regression is highest in such models.

Together with the estimated Taylor rules and the non-nested tests, a total of 136 regressions is estimated. The methodology we adopt to identify the data...
congruent model falls in two parts. The first part is to pin down the correct inflation measure. The second part is to pin down the output measure. The first part consists of

Table 1

Estimated Reaction Functions

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Note: The first column represents the output gap measures: CBO=CBO output gap, HP=Hodrick-Prescott Trend Filter output gap, TAYLOR=Taylor's Linear Time Trend output gap, IMF=IMF's output gap. The second column represents the inflation gap measures: CPI=CPI Inflation, CORE/Core CPI Inflation, DEF=GDP Price Inflation, UMICH=University of Michigan Expected Inflation, FED=Philadelphia Fed Expected Inflation. $\rho_0$ represent AR(1) errors, $\sigma$ represents the standard error of the regression, t-statistics, are shown in parentheses, ** and * denote significant at the 1 and 5 percent levels respectively.

Picking any one measure of output gap among the four measures and use the five different inflation measures each alternatively to estimate non-nested Taylor-type rules. We then perform the non-nested pair-wise P test as well as the joint test. The null hypothesis in the pair-wise test consists of testing one measure of inflation against another measure of inflation for a given output gap measure whereas the null hypothesis in the joint test consists of testing one measure of inflation against all the other measures of inflation for a given output gap measure. Then the procedure is repeated for each of the other three output gap measures. The objective is to pin down the correct inflation measure(s) for each output gap measure. For any single one output gap measure and five inflation measures this means there are 20 pair-wise P
tests (as this involves the reverse P test also) and 5 joint P tests. This makes a total of 100 non-nested P tests for the four output gap measures and the five inflation measures we have. Furthermore, with five inflation measures, we have 5 own regressions for each output gap measure. Thus, the number of estimated regressions to pin down the correct inflation measure totals 120.

Table 2 shows the results of the P tests for different measures of inflation against the CBO measure of output gap, the Hodrick-Prescott Trend measure of output gap, Taylor’s linear time trend measure of output gap and the IMF’s measure of output gap respectively. One important result from table 2 is that there is strong evidence to suggest that the Philadelphia Fed measure of expected inflation is the most robust measure of inflation for policy rule specification. Rule recommendations based on this measure of inflation most closely and most appropriately describe the behavior of the Fed Funds rate. This result is strikingly clear and unambiguous and holds irrespective of which measure of output gap is used. The GDP price inflation which is usually used in the literature on policy rules gets rejected consistently almost everywhere against the Philadelphia Fed expected inflation measure, and this calls for attention that using the GDP price inflation measure in policy rules would lead to a misspecification bias.

In Panel A, the Philadelphia Fed measure of expected inflation cannot be rejected in pair-wise tests against any of the other inflation measures except in the one case of GDP price inflation. It cannot also be jointly rejected against all of the other measures of inflation, the joint Wald test statistic being 1.39 and insignificant.
Table 2
Non-Nested P Tests to Identify the Inflation Measure

<table>
<thead>
<tr>
<th>Panel</th>
<th>Output</th>
<th>Null Inflation</th>
<th>Alternative Hypotheses</th>
<th>Joint Test</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>CPI</td>
<td>CORE</td>
<td>DEF</td>
</tr>
<tr>
<td>CBO</td>
<td>CPI</td>
<td>0.44</td>
<td>0.09</td>
<td>2.50**</td>
</tr>
<tr>
<td>CBO</td>
<td>CORE</td>
<td>1.95</td>
<td>0.45</td>
<td>3.24**</td>
</tr>
<tr>
<td>A</td>
<td>CBO</td>
<td>0.46</td>
<td>-0.37</td>
<td>0.42</td>
</tr>
<tr>
<td>CBO</td>
<td>DEF</td>
<td>1.46</td>
<td>1.00</td>
<td>2.84**</td>
</tr>
<tr>
<td>CBO</td>
<td>UMICH</td>
<td>1.38</td>
<td>1.30</td>
<td>2.20**</td>
</tr>
<tr>
<td>CBO</td>
<td>FED</td>
<td>0.44</td>
<td>0.23</td>
<td>2.51**</td>
</tr>
<tr>
<td>HP</td>
<td>CPI</td>
<td>1.75</td>
<td>0.45</td>
<td>3.18**</td>
</tr>
<tr>
<td>HP</td>
<td>CORE</td>
<td>0.16</td>
<td>-0.85</td>
<td>0.42</td>
</tr>
<tr>
<td>B</td>
<td>HP</td>
<td>1.13</td>
<td>1.08</td>
<td>2.59**</td>
</tr>
<tr>
<td>HP</td>
<td>FED</td>
<td>0.28</td>
<td>-0.67</td>
<td>1.37</td>
</tr>
<tr>
<td>TAYLOR</td>
<td>CPI</td>
<td>0.43</td>
<td>-0.24</td>
<td>2.08**</td>
</tr>
<tr>
<td>TAYLOR</td>
<td>CORE</td>
<td>1.90</td>
<td>0.43</td>
<td>2.99**</td>
</tr>
<tr>
<td>C</td>
<td>TAYLOR</td>
<td>0.42</td>
<td>-1.14</td>
<td>0.42</td>
</tr>
<tr>
<td>TAYLOR</td>
<td>UMICH</td>
<td>1.06</td>
<td>0.64</td>
<td>2.29**</td>
</tr>
<tr>
<td>TAYLOR</td>
<td>FED</td>
<td>0.89</td>
<td>-0.21</td>
<td>1.74</td>
</tr>
<tr>
<td>IMF</td>
<td>CPI</td>
<td>0.46</td>
<td>-0.19</td>
<td>1.87</td>
</tr>
<tr>
<td>IMF</td>
<td>CORE</td>
<td>2.31**</td>
<td>0.47</td>
<td>2.87**</td>
</tr>
<tr>
<td>D</td>
<td>IMF</td>
<td>1.69</td>
<td>0.82</td>
<td>2.42**</td>
</tr>
<tr>
<td>IMF</td>
<td>FED</td>
<td>1.69</td>
<td>1.24</td>
<td>2.45**</td>
</tr>
</tbody>
</table>

Note: The first column represents the output gap measures: CBO=CBO output gap, HP=Hodrick-Prescott Trend Filter output gap, TAYLOR=Taylor’s Linear Time Trend output gap, IMF=IMF’s output gap. The second column represents the null hypotheses for the different inflation gap measures: CPI=CPI Inflation, CORE=Core CPI Inflation, DEF=GDP Price Inflation, UMICH=University of Michigan Expected Inflation, FED=Philadelphia Fed Expected Inflation. The alternative hypotheses are given in columns 3 to 7. Numbers in the last column are the Joint tests results, off diagonal cells represent t-statistics, diagonal cells represent the standard error of the regression, and ** denotes significant at the 1 percent level.
In practical terms, this means that the Philadelphia Fed measure of expected inflation encompasses the other inflation measures. That is, it appropriately characterizes the Fed Funds rate data generating process in a Taylor-type setting while the other inflation measures add no extra value. The CPI inflation measure is rejected against GDP price inflation as well as the Philadelphia Fed measure of expected inflation. The GDP price inflation is rejected against only the Philadelphia Fed expected inflation measure in the pair-wise test, but rejected in the joint test. The University of Michigan expected inflation measure is rejected against both the GDP price inflation and the Philadelphia Fed expected inflation measures. The core CPI inflation seems to be the worst measure of inflation in the monetary policy rule setting as it is rejected against all but one of the other inflation measures. Similar results for the joint tests carry through Panels B to D.

Panel B shows the results of the P tests in a similar spirit as in Panel A. Here, the Taylor-type rules have been estimated using the Hodrick-Prescott filter trend measure of the output gap. Again, the Philadelphia Fed expected inflation measure cannot be rejected against any of the other inflation measures either in a pair-wise fashion or jointly. The CPI, the core CPI inflation and the University of Michigan expected inflation measures are rejected against most of the other inflation measures. The GDP price inflation, however, is rejected only against the Philadelphia Fed expected inflation measure in the pair-wise P test. The results in Panel C where the Taylor-type rules are estimated using the Taylor's linear time trend measure of output gap follow very closely the pattern in Panel B. The Philadelphia Fed expected
inflation measure is the most robust measure of inflation. When the IMF measure of output gap is used as shown in Panel D, the core CPI is rejected against all of the other inflation measures. The CPI and the GDP price inflation are rejected against only the Philadelphia Fed expected inflation measure. The result that the Philadelphia Fed inflation measure is still robust is maintained here also.

Besides the fact that the Philadelphia Fed expected inflation measure shows up as an outstanding inflation measure for policy rules, there is also evidence from the four panels that irrespective of the output gap measures used, the core CPI inflation as a measure of inflation for rule recommendations seems to be the worst measure: it is rejected by almost all other measures of inflation in a pair-wise fashion as well as jointly.

Once having pinned down the Philadelphia Fed expected inflation measure as the inflation measure which is consistent with the interest rate data generating process, we go on to the second part to pin down the correct output gap measure(s). Using the Philadelphia Fed expected inflation measure, we now estimate non-nested Taylor rules with varying output gap measures. With four output gap measures, this means we have to perform 12 pair-wise and 4 joint P tests, making a total of 16 non-nested P tests.

Table 3 shows the results of Taylor rules-based P test for different measures of output gap against the Philadelphia Fed expected inflation measure.
Table 3
Non-Nested P Tests to Identify the Output Gap Measure

<table>
<thead>
<tr>
<th>Null Hypotheses</th>
<th>CBO</th>
<th>HP</th>
<th>TAYLOR</th>
<th>IMF</th>
<th>Joint Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>CBO</td>
<td>0.39</td>
<td>0.48</td>
<td>0.34</td>
<td>-1.86</td>
<td>1.56</td>
</tr>
<tr>
<td>HP</td>
<td>1.84</td>
<td>0.40</td>
<td>0.79</td>
<td>0.46</td>
<td>2.36*</td>
</tr>
<tr>
<td>TAYLOR</td>
<td>2.62**</td>
<td>1.66</td>
<td>0.40</td>
<td>0.09</td>
<td>2.72**</td>
</tr>
<tr>
<td>IMF</td>
<td>4.06**</td>
<td>3.35**</td>
<td>2.96**</td>
<td>0.43</td>
<td>5.53**</td>
</tr>
</tbody>
</table>

Note: This table conditions on the fact that the inflation measure is the Philadelphia Fed expected inflation identified in table 2. The first column represents the null hypotheses for the different output gap measures: CBO=CBO output gap, HP=Hodrick-Prescott Trend Filter output gap, TAYLOR=Taylor’s Linear Time Trend output gap, IMF=IMF’s output gap. Numbers in the last column are the Joint tests, off diagonal cells represent t-statistics, diagonal cells represent the standard error of the regression, ** and + denote significant at the 1 percent and 8 percent levels respectively.

The results are again strong and unambiguous: the CBO output gap measure cannot be rejected against any of the other measures of output gap either in a pairwise fashion or jointly. This means that the CBO measure of output gap encompasses the other output gap measures. However, there is slight evidence that the Hodrick-Prescott Trend measure of output gap can be at best only a weak proxy for the output gap in rule recommendations: it cannot be rejected until the 8 percent level of significance. Taylor’s linear time trend measure and the IMF’s measure of output gap are strongly rejected, with the IMF’s measure being the worst measure of output gap to be used in rule recommendations.
Conclusion

This paper has focused on identifying a monetary policy rule that most appropriately describes the Fed Funds rate data generating process. We have used a class of non-nested Taylor-type rules, employed the encompassing principle and performed 116 non-nested P tests to examine their data congruency. Of the various backward-looking and forward-looking measures of inflation and output gap that have been traditionally claimed to be relevant for monetary policy design, our study shows that only the Philadelphia Fed measure of expected inflation as calculated by the Survey of Professional Forecasters and the CBO measure of output gap are the measures that produce the rule recommendations that are consistent with the actual Fed Funds rate over the 1983Q1 to 2002Q2 period. This means that rule recommendations based on these measures alone most closely mimic the actual Fed Funds rate behavior. Moreover, Taylor-type rules estimated with these measures encompass alternative models. This implies that the results are robust and the model that uses the Philadelphia Fed expected inflation measure and the CBO output gap measure is data congruent. The fact that the Philadelphia Fed measure of inflation is an expected measure this has implications for the debate about the forward-looking behavior of Taylor-type rules.
PART IV

DOES THE FED REACT TO ASSET PRICES
WHILE DESIGNING MONETARY POLICY?

Introduction

The relationship between monetary policy and asset prices has received increased attention over the past two decades. Two recent developments could potentially change the way monetary policy has traditionally been viewed: one is stock price volatility and the other is productivity gains. The bull market that began in 1983 (Balke and Wolhar, 2001) has led economists to ask whether fundamentals have changed or the market is high only because of some irrational exuberance as Federal Reserve (Fed) Chairman Alan Greenspan noted in his December 1996 speech. A change in market fundamentals in the form of sustainable productivity gains has very different implications from simply a transient misalignment of asset prices. Moreover, while volatility in part reflects the nature of asset prices (driven primarily by revisions in expectations of future returns), large movements have important implications as they pose a threat to price stability which is the overriding goal of monetary policy.

If asset prices contain vital information about the economy the logical question, therefore, is: Do asset prices influence the design of monetary policy? The existing debate has revolved more around analyses of monetary policy prescriptions than realized monetary policy actions without giving enough emphasis to the latter.
Should the Fed systematically react to asset price movements is indeed a different, though not unrelated, question from does the Fed react to asset price movements? There are episodes in history that suggest that the Fed did respond to asset prices. For instance, the 1987 policy easing in response to the stock market crash and, more recently, the series of interest rate hikes that the Fed undertook as stock prices escalated to unprecedented levels in the late 1990s. However, cases like these are most often discussed as "discretionary" in the rules-versus-discretion debate. This raises the issue of what variables enter monetary policy rules in a dynamic and continuously evolving financial and economic environment. To understand what policy should be, it is important to first know what policy has been, so that mistakes are not repeated as lessons are drawn. This paper is an attempt to shed light on these issues by analyzing whether the monetary policy reacts to the stock market. In the literature, when analyses of stock markets and monetary policy have been undertaken, adequate distinction has not been made between stock price bubbles, stock returns volatility and stock market fundamentals. One contribution of this study is to highlight that these issues are indeed different and have different policy implications.

Since Taylor (1993), monetary policy has been modeled as interest rate feedback rules or reaction functions whereby the Fed changes its policy instrument, the nominal Federal Funds rate, in response to variables in the economy, in particular, inflation and output variability. Difficulties in measuring money and finding a stable money demand function are the reasons why interest rates are favored over the money supply rule (Poole, 1970). Taylor (1993) argues that his simple rule is a good
representation of how the Fed sets its policy instrument. However, critics have shown that the so-called Taylor rule misses out on the inertial behavior of the Fed and this has led to an enormous literature on optimal policy rules as opposed to simple policy rules (Giannoni and Woodford, 2001). Yet, among the class of optimal policy rules, there is a division about how these rules are specified especially when it comes to the possibility of the Fed's reaction to asset price movements.

A number of authors have recently cautioned against the incorporation of asset prices in monetary policy feedback rules (Fuhrer and Moore (1992), Woodford (1994), Bernanke and Gertler (1999, 2001), and Bullard and Schaling (2002)). Their reasoning is that targeting asset prices have undesirable effects. Bernanke and Gertler (1999, 2001) argue that it is desirable for central banks to focus on underlying inflationary pressures and asset prices become relevant only to the extent they may signal potential inflationary or deflationary forces. They conclude that as long as monetary policy responds aggressively to inflation, there is no rationale for a direct response to asset prices. Bullard and Schaling (2002) show in a simple arbitrage model that responding to equity prices results in indeterminacy of rational expectations equilibrium. Fuhrer and Moore (1992) find that placing too much weight on asset prices in the reaction function may lead to instability as policy loses control of inflation. Similarly, Woodford (1994) and Bernanke and Woodford (1997) show that automatic monetary policy feedback from such indicators can create instability due to self-fulfilling expectations.

However, some studies such as Kent and Lowe (1997), Smets (1997),
Carlstrom and Fuerst (2000), Rigobon and Sack (2001), Becchetti and Mattesini (2001) and Cecchetti et al (2000) support the idea that central banks react to asset price movements. Examples of such studies are. The idea is that a central bank concerned with stabilizing inflation about a specific target level is likely to achieve superior performance by adjusting its policy instruments not only in response to its forecast of future inflation and the output gap, but to asset prices as well. Cecchetti et al (2000) reason that asset price bubbles create distortions in investment and consumption, leading to extreme rises and then falls in both output and inflation. Raising interest rates modestly as asset prices rise above what are estimated to be warranted levels, and lowering interest rates modestly when asset prices fall below warranted levels helps to smooth these fluctuations by reducing the possibility of an asset price bubble coming into existence in the first place. Kent and Lowe (1997) argue that if the central bank can reduce the size of the bubble by tightening policy when the bubble is still in its formative stages, the imbalances created when it eventually bursts will be mitigated. Becchetti and Mattessini (2001) construct an Index of Stock Price Misalignment based on a discounted cash flow model and show that the Fed reacts to deviations from fundamental values by raising the Federal Funds rate. Rigobon and Sack (2001) also find that the Fed reacts to changes in stock market valuations when adjusting its instrument. Using a monetary model with flexible nominal prices, Carlstrom and Fuerst (2000) show that to the extent that asset prices do not immediately lead to price inflation, there is a welfare-improving role for a monetary policy that responds actively to asset price and productivity shocks. Smets
(1997) suggests that the optimal monetary response to unexpected changes in asset prices depends on how these changes affect the central bank’s inflation forecast; if they imply a rise in the inflation forecast, policy should be tightened and vice versa. However, his evidence suggests that the Bank of Canada responds to a rise in the stock prices by lowering interest rates.

Overall, not only are there divergent views about whether monetary policy reacts to asset prices, but also there is another dimension to the problem, namely how to estimate asset price misalignments or gauge the amount of volatility that asset price movements contain? Another purpose of this paper is to address these issue.

The contributions of this study are, therefore, two-fold. First, this paper uses a non-linear model of intrinsic bubbles to isolate market fundamentals from asset price misalignments. The estimated measures of fundamental values of stocks and asset price bubbles are then used in an augmented Taylor rule to assess the Fed’s response. As fundamental values are essentially driven by productivity, this paper also uses a more direct measure of productivity growth to assess the robustness of the Fed’s reaction. Productivity has surprisingly not been modeled explicitly in Taylor rules and this paper shows that unlike standard variables that enter Taylor rules, productivity or market fundamentals have very different implications for policy, as Koenig (2000) would agree. Second, this paper provides an estimate of asset returns volatility by using an Exponential Generalized Autoregressive Conditional Heteroskedastic (E-GARCH) model. The attractive feature of this model is that it captures the asymmetries – the leverage effects – that are inherent in the volatility of stock returns.
This estimated measure of volatility is then also used as an additional variable in the Taylor rule.

Measuring Stock Market Fundamentals, Bubbles and Volatility

Stock prices and returns have the inherent characteristic of being volatile partly because they are driven by frequent revisions in market expectations. However, when volatility tends to be large there is a cause for concern and the question that arises is: To what extent does movement in stock prices reflect changes in fundamental values? The simple present value model, which states that real stock prices depend linearly on real dividends, is clearly inadequate. Indeed, Shiller (1981) shows that stock prices are too volatile to be explained by movements in dividends alone. Barsky and De Long (1993) and Campbell and Shiller (1987) also support this view that stock prices respond more than proportionately to movements in dividends. This suggests that stock prices tend to have another component besides fundamental values. In fact, West (1987) shows that the stock price equals the sum of two components: the price implied by the efficient markets model (Fama, 1970) and a speculative bubble. According to Stiglitz (1990), a stock price bubble exists if the reason that the price is high today is only because investors believe that the selling price will be high tomorrow. Hence, bubbles represent price misalignments or deviations of stock market price from fundamental values.

Attempts to explain fundamental values can be traced back to Gordon (1962). However, one of the most influential works on stock market bubbles is that of Froot
and Obstfeld (1991). They develop a model of intrinsic bubbles for stock prices. Using this intrinsic bubble framework, we extract the fundamental value of stocks and a measure of stock price misalignments that we use subsequently in this study.

Intrinsic Bubbles and Fundamental Values of Stocks

According to Froot and Obstfeld (1991), an intrinsic bubble is a rational bubble (defined below) that depends exclusively – albeit nonlinearly – on dividends. It is called intrinsic because it derives all of its variability from exogenous fundamental determinants of asset prices (that is dividends). One important feature of intrinsic bubbles is that they are deterministic functions of dividends alone. Thus this class of bubbles predicts that stable and highly persistent fundamentals lead to stable and highly persistent over- or under-valuations. In addition, these bubbles can cause asset prices to “overreact” to changes in fundamentals. Froot and Obstfeld (1991) start out with a simple present value condition where the real stock price is equal to the present discounted value of real dividend payment plus the real stock price next period:

\[ P_t = e^{-r} E_t (D_t + P_{t+1}) \]

where \( P_t \) is real price of a share at the beginning of period \( t \), \( D_t \) is real dividends per share paid out over period \( t \), \( r \) is the constant real discount rate, and \( E_t(.) \) is the market’s expectation conditional on information known at the start of period \( t \). The present value solution for \( P_t \), denoted \( P_t^{\text{PV}} \), is

\[ P_t^{\text{PV}} = \sum_{s=t}^{\infty} e^{-r(s-t+1)} E_t(D_s). \]
A rational bubble $B_t$ is one that satisfies

$$B_t = e^{-r} E_t(B_{t+1}).$$

Then, equation (16) can be written as

$$P_t = P_t^{PV} + B_t$$

which can be thought of as the sum of the present-value solution and a rational bubble. Rational bubbles are sometimes viewed as being driven by variables extraneous to the valuation problem. However, Froot and Obstfeld (1991) argue that some bubbles may depend only on the exogenous fundamental determinants of asset value. An intrinsic bubble is constructed by finding a nonlinear function of fundamentals that satisfies (18). For this, they assume that log dividends are generated by the geometric martingale

$$d_{t+1} = \mu + d_d + \xi_{t+1}$$

where $\mu$ is the drift in dividends, $d_t$ is the log of dividends at time $t$, and $\xi_{t+1}$ is a normal random variable with conditional mean zero and variance $\sigma^2$. Using (20) and assuming that period-$t$ dividends are known when $P_t$ is set, we see that the present value stock price in (17) is directly proportional to dividends:

$$P_t^{PV} = \kappa D_t$$

where $\kappa = 1/(e^r - e^\mu - \frac{\sigma^2}{2})$.

Equation (21) is essentially a stochastic version of Gordon's (1962) model of stock prices, which predicts that $P_t^{PV} = D_t / (e^r - e^\mu)$ under certainty. The assumption that the sum in (17) converges implies that $r > \mu + \frac{\sigma^2}{2}$. Now, an intrinsic bubble is
defined as

\[ B(D_t) = cD_t^x \]  

where \( \lambda \) is the positive root of the quadratic equation \( \lambda^2 \sigma^2/2 + \lambda \mu - r = 0 \), and \( c \) is an arbitrary constant. By summing the present value price (21) and the bubble in (22), we get our basic stock price equation:

\[ P(D_t) = P_{tpv} + B(D_t) = kD_t + cD_t^x. \]

Equation (23) says that the price of stocks has two components: the fundamental value, which depends linearly on dividends, and the intrinsic bubble which depends on dividends in a nonlinear fashion. For \( c > 0 \), stock prices will over-react to changes in dividends:

\[ \frac{dP_t}{dD_t} = \kappa + \lambda cD_t^{x-1} > \kappa \]

In order to estimate the fundamental value and the bubble component in (23), the following statistical model is used

\[ P_t = kD_t + cD_t^x + \epsilon_t, \]

where \( \epsilon_t \) is the present value errors. Estimating equation (25) poses problem because of collinearity among the regressors. So, dividing equation (25) throughout by \( D_t \) gives:

\[ \frac{P_t}{D_t} = \kappa + cD_t^{x-1} + \eta_t, \]

where \( \eta_t = \epsilon_t/D_t \). In equation (26) focus is on intercept term \( \kappa \). Once the value of \( \kappa \) is obtained, the fundamental value of stocks from equation (21) can be estimated as
\( P_{t}^{pv} = \kappa D_{t} \). Then an estimate of the bubble would be \( B(D_{t}) = P_{t} - P_{t}^{pv} \) or \( cD_{t}^{A} \).

This study uses quarterly data from 1985:1 to 2001:3 for the U.S. economy. All the data are in 1996 constant prices and seasonally adjusted, except for the interest rate. Data on dividends and stock prices (Standard & Poor’s 500) are taken from Shiller (2000). We have deflated them using the Consumer Price Index with 1996 as the base year. These monthly data have been converted to quarterly data using normal aggregation procedures. Stock returns are calculated as the log difference of real stock prices.

To estimate equation (26), the non-linear least squares method is employed. The objective is to come up with an optimal value of \( \lambda - 1 \) that minimizes the sum of squared residuals (SSR) from equation (26). This is done by using a grid search, starting out with values of \( \lambda - 1 \) that Froot and Obstfeld computed (which is approximately 3). However, because of the non-linear property of the equation, convergence was the main problem that occurred. Moreover, in this study quarterly data are used whereas they used annual data, and this created some technical issues that need to be resolved by a grid search. Experiments are done with extreme values for \( \lambda - 1 \) ranging from 1 to 50 with increments of 1 unit at a time. The criterion to include incremental points is whether each increment is adding to the efficiency of the SSR. After pinning down the initial value of \( \lambda - 1 \), equal to 13, which gives a local minimum, a finer grid search with increments of 0.1 unit is used. This is the second round of the grid search. The optimal \( \lambda - 1 \) that is extracted turns out to be 12.70. The results are reported in Table 4.
Table 4

Grid Search for Optimal $\lambda$-1

<table>
<thead>
<tr>
<th>First Round</th>
<th>Second Round</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\lambda$-1</td>
<td>SSR</td>
</tr>
<tr>
<td>9.00</td>
<td>11963.15</td>
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<tr>
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<td>13.00</td>
<td>10949.14</td>
</tr>
<tr>
<td>14.00</td>
<td>11043.43</td>
</tr>
</tbody>
</table>

Note: SSR=sum of squared residuals

Corresponding to this value of $\lambda$-1, the estimate of $\kappa$ is 25.48 and it is significant with a t-ratio of 38. Froot and Obstfeld (1991) estimated $\kappa$ to be 14. Their estimate is lower than the one reported here and may be due to the fact that their sample consists of annual data for the 1900-1988 period only; this excludes the recent periods of asset price booms. Balke and Wolhar (2001) extracted a fundamental value of 24.91 for a very long historical sample period (from 1881 to 1999), by using the Gordon's (1962) stock valuation model. For the 100-year period before 1983, they extract a price-dividend ratio which is not very dissimilar.

Using the estimated $\kappa$ value of 25.48, the fundamental value of stocks is then given by $P_t^{PV} = 25.48D_t$. Figure 3 shows a plot of the log of actual real stock prices and the log of the estimated fundamental value of stocks. The striking feature in Figure 3 is the huge bubble that occurred in the late 1990s: real stock prices are way above their fundamental values. That stocks were over-valued in the 1990s is well supported by our data.
The plot also shows the (recessionary) years around 1980 to be a period where stocks were under-valued. It can be noticed that historically it appears that fundamental values and asset prices tend to have a strong correlation until the early 1990s. However, because of frequent revisions in expectations, asset prices tend to have a volatile component as well. In the 1990s asset prices have departed drastically from fundamental values as we can see from Figure 3. The implication of such a misalignment or asset bubble is that if fundamental values tend to have the same growth path, then it means that asset prices should revert back to it in the coming years, all else constant. The bursting of the bubble is indeed a cause for concern for the Fed as these certainly have implications for price stability.
Volatility of Stock Returns

While many studies have recognized that volatility in asset prices or returns are a cause for concern, none of them has integrated a systematic measure of volatility into a monetary policy rule. In their study on monetary policy and asset price volatility, Bernanke and Gertler (1999) model volatility as the once-lagged log level of the stock price relative to its steady-state value \([\log(S_{t-1}/S)]\). In their empirical model they use the log-differenced change in stock prices to capture this. While this is traditionally used as a proxy for volatility, a more appropriate method of measuring volatility would be the Exponential Generalized Autoregressive Conditional Heteroskedastic (E-GARCH) model proposed by Nelson (1991). The E-GARCH model has the property that it can capture the asymmetries in volatility which are typically observed in asset returns.

The E-GARCH model is an extension of the ARCH model introduced by Engle (1982) and generalized as GARCH (Generalized ARCH) by Bollerslev (1986). In the standard GARCH(1,1) specification

\[
(27) \quad y_t = x_t \gamma + \varepsilon_t,
\]

\[
(28) \quad \sigma_t^2 = \omega + \alpha \varepsilon_{t-1}^2 + \beta \sigma_{t-1}^2,
\]

the mean equation given in (27) is written as a function of exogenous variables, \(x_t\), with an error term, \(\varepsilon_t\), which has conditional mean zero and variance \(\sigma_t^2\) given by (28). Since \(\sigma_t^2\) is the one-period ahead forecast variance based on past information, it represents the conditional variance. The conditional variance equation specified in
(28) is a function of three terms: the mean, $\omega$; news about volatility from the previous period, measured as the lag of the squared residual from the mean equation, $\varepsilon^2_{t-1}$ (the ARCH term), and the last period’s forecast variance, $\sigma^2_{t-1}$ (the GARCH term).

However, for equities, it is often observed that downward movements in the market are followed by higher volatilities than upward movements of the same magnitude – the so-called leverage effect. To account for this asymmetry, Nelson (1991) proposed an E-GARCH model where the specification for the conditional variance is:

\[
\log(\sigma_t^2) = \omega + \beta \log(\sigma_{t-1}^2) + \alpha \frac{|\varepsilon_{t-1}|}{\sigma_{t-1}} + \gamma \varepsilon_{t-1}. 
\]

Since the left-hand side is the log of the conditional variance, this implies that the leverage effect is exponential, rather than quadratic, and that forecasts of the conditional variance are guaranteed to be nonnegative. Leverage effect exists if $\gamma < 0$. The impact is asymmetric if $\gamma \neq 0$.

Before equation (29) can be estimated, an AR process for the stock returns (log differenced of real stock prices) is fitted to make it stationary. Monthly stock returns data of the S&P500 index from 1955:01 to 2002:07 are used because we want to capture the maximum information contained in the higher frequency data. The results suggest that an AR(1) process adequately describes the data (the correlogram and Q-statistics for lags up to 36 indicate no serial correlation). Then an AR(1)-E-GARCH(1,1) process is estimated and the results are:
\[
\log(\sigma_t^2) = -1.928 + 0.729\log(\sigma_{t-1}^2) + 0.089\frac{\varepsilon_{t-1}}{\sigma_{t-1}} - 0.261\frac{\varepsilon_{t-1}}{\sigma_{t-1}}
\]

(0.375) (0.055) (0.052) (0.047)

The figures in parentheses are the Bollerslev-Wooldrige robust standard errors. The estimated value of \(\gamma\) (-0.261) is negative and significant at the 1 percent level, indicating the existence of the leverage effect in stock returns. Bad news \((\varepsilon_{t-1}/\sigma_{t-1}<0)\) and good news \((\varepsilon_{t-1}/\sigma_{t-1}>0)\) have differential impacts on the conditional variance – bad news creating more volatility than good news. The estimated monthly conditional variance series is then converted to a quarterly series using standard aggregation method to match the frequency of other variables in the estimated reaction functions. This conditional variance series \(\sigma_t^2\) forms the basis of our measure of volatility of stock returns used in the analysis of monetary policy rules. Figure 4 shows the volatility of stock returns plot.

It can be noticed that stock market volatility displays a strong counter-cyclical pattern – peaking just before or during recessions and falling sharply late in recessions or early in recovery periods. Moreover, when volatility increases, investors require a higher risk premium to hold stocks. As a result, stock prices fall. This is evident in the 1987 stock market crash, the 1990 Persian Gulf and S&L crises and recession, the 1994 Mexican Peso Crisis, the 1998 Russian Default and the 2001 recession.
Figure 4. Volatility of Stock Returns

The movement in volatility also appears to be persistent: once volatility rises, it usually stays at high levels for a while. However, it shows no apparent long-run trend. After declining in the early 1990s, volatility started to rise in 1996 and since then has remained at remarkably high levels by postwar standards. As pointed out by some authors in the literature, although unusual, the prolonged period of high volatility appears to be the result of a string of specific events. The East Asian crisis and the Russian bond default ignited financial market turmoil in 1997 and 1998, which persisted through 1999. Stock market volatility rose again in 2000 and 2001, and stock prices fell, when analysts began to forecast an end to the long economic expansion. Interestingly, the volatility of the stock market took a large dip in the
fourth quarter of 2001.

Estimated Augmented Taylor Rules

Several reaction functions reported in Table 5 are estimated based on an augmented Taylor rule using the following model specification:

\[ i_t = r^f + g_\pi (\pi_t - \pi^*) + g_y y_t + g_z z_t \]

where \( z_t \) contain the additional variables we include in the reaction function. The Federal Funds rate (FFR) is the nominal interest rate aggregated from monthly data, obtainable from the Board of Governors of the Federal Reserve System. In a previous study we showed that the appropriate measures of inflation and output gap that enter monetary policy rules are the Philadelphia Fed measure of expected inflation and the Congressional Budget Office (CBO) output gap. The Philadelphia Fed measure of expected inflation is the one-year ahead average inflation forecast for chain-weighted GDP price index as reported by the Survey of Professional Forecasters. The inflation gap (INFLA) is the deviation of this measure of expected inflation from a target of 2 percent. The output gap (YGAP) is the percentage deviation of real GDP from potential GDP where potential GDP is the CBO measure of potential output. Data on productivity (PROD) is the productivity index measured as output per hour of all persons from the Bureau of Labor of Statistics, U.S. Department of Labor. Productivity growth (PRODGR) is the log difference of PROD. As the starting point, we consider the case where the variable \( z_t \) represents only the lagged Federal funds...
rate (FFR-1). This gives the regular augmented Taylor rule model with inertial behavior. The results are shown in column (1) in Table 5.

Table 5
Estimated Augmented Taylor Rules

<table>
<thead>
<tr>
<th>Panel A</th>
<th>Models</th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
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<td>INFLA</td>
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<td>0.329*</td>
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<td></td>
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<td>(2.48)</td>
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<td>FFR-1</td>
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<tr>
<td>VOL</td>
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<td></td>
<td>(-1.61)</td>
<td>(-2.29)</td>
<td></td>
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<td>-0.005**</td>
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<td>(-4.30)</td>
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<table>
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<th>Panel B</th>
<th>Models</th>
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<th>(6)</th>
<th>(7)</th>
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<th>(9)</th>
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<td>0.565**</td>
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<tr>
<td></td>
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<td>0.420**</td>
<td>0.438**</td>
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<td></td>
<td>(5.03)</td>
<td>(6.68)</td>
<td>(5.35)</td>
<td>(7.63)</td>
<td>(0.438)</td>
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<tr>
<td>FFR-1</td>
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<td>0.657**</td>
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<tr>
<td></td>
<td>(6.79)</td>
<td>(10.37)</td>
<td>(7.55)</td>
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<td>(10.24)</td>
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<tr>
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<td>(-2.12)</td>
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<tr>
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<td>-0.004**</td>
<td>-0.005**</td>
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</tr>
<tr>
<td></td>
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<td></td>
<td>(-3.58)</td>
<td>(-4.90)</td>
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<td>FV25</td>
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<td>-2.970*</td>
<td>-1.107</td>
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<td>(-1.03)</td>
<td>(-2.46)</td>
<td>(-1.27)</td>
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<tr>
<td>PROGR</td>
<td></td>
<td></td>
<td>-0.094*</td>
<td></td>
<td></td>
<td>(-1.78)</td>
</tr>
</tbody>
</table>

Note: t-statistics are shown in parentheses. *, ** and *** denote significant at the 10 percent, 5 percent and 1 percent levels respectively. Regressions have been corrected for first order serial correlation.
As it can be seen, all the coefficients are highly significant and have the expected signs. Rudebusch (2002) shows that by using an interest rate smoothing rule of the following type

\[(32) \quad i_t = (1 - \rho) (g_\pi \pi_t + g_y y_t) + \rho i_{t-1}\]

we can extract the \(g_\pi\) and \(g_y\) coefficients. Column (1) in Table 5 indeed implies that

\[(33) \quad i_t = (0.34)(g_\pi \pi_t + g_y y_t) + 0.66 i_{t-1}\]

so that \(g_\pi = 2.44\) and \(g_y = 0.79\). This result accords with the standard literature that the Fed should respond to inflation by increasing interest rate by a more than one-to-one ratio for policy to be stabilizing (Taylor, 1999). A coefficient of more than 1.3 is usually considered aggressive.

As far as stock returns in reaction functions are concerned, Bernanke and Gertler (1999) argue that there are two ways to interpret them. The first is to interpret them as literally saying that monetary policy is reacting directly to stock prices, as well as to the output gap and expected inflation. The second is to treat the addition of stock returns as a general specification test that reveals whether monetary policy is pursuing other objectives besides stabilization of output and expected inflation. To the extent that policy has other objectives, and there is information about these objectives in the stock market, then we would expect to see stock returns enter the central bank's reaction function with a statistically significant coefficient.

Column (2) in Panel A of Table 5 shows that the bubble term (BUB), calculated as the percentage deviation of real stock prices from fundamental values estimated earlier, is statistically significant. However, this result has to be interpreted with
caution as some elements of fundamentals might be present in the bubble measure which is essentially an intrinsic bubble driven by dividends. Moreover, the magnitude of the coefficient is very small that its economic significance from a policy perspective is not fully warranted. Bernanke and Gertler (1999) found a negative but insignificant coefficient for their measure of asset price bubbles and they claim that the Fed does not and should not react to stock returns unless these signal potentially inflationary or deflationary pressures. The notion that the Fed attempts to burst a bubble by raising rates when a bubble appears does not seem to be supported by the data.

To see how the Fed responds to asset price volatility, the measure of volatility from the E-GARCH model estimated earlier (VOL) is used as an additional variable in the Taylor rule. The results show that the VOL variable in column (3) is negative but statistically insignificant. However when both volatility and asset bubbles are included in the reaction function they turn out to be highly significant as shown in column (4). Various specifications are estimated by using some of the variables in combination with others and some alone as regressors. The aim is to maintain the goal of parsimony.

In column (8) and (9) when other regressors are included as well, the volatility variable enters significantly and negatively. This suggests that the Fed lowers interest rate in response to a rise in volatility in asset returns. The argument that can be made here is that a rise in volatility creates unstable economic environment as the level of uncertainty rises and businesses and firms lose confidence in economic activity. In
order to establish confidence back in the markets, the Fed follows an expansionary policy by lowering rates. This potentially boots consumption and investment and general economic activity. Such a policy was evident in the 1987 stock market crash and the 2001 contraction. On the other hand, suppose initially there was a reduction in volatility. This means that investors require a lower risk premium to hold stocks, so stock prices rise. If this rise in stock prices signals a recovery which can lead to wealth effects and inflationary pressures, the Fed might be tightening policy. The results contrast with Cecchetti et al (2000) who argue that the Fed should raise rates in response to asset price misalignments and volatility.

In columns (5) to (8) in Panel B the fundamental value of assets (FV25) in conjunction with the volatility (VOL) variable or alone are used as regressors in the Fed’s reaction function to see how the Fed reacts to a change in market fundamentals in the presence and absence of volatility. On balance, both turn out to be negative and significant. Indeed, a rise in the fundamental value of stocks is due to higher dividend growth and higher productivity which means lower inflationary pressures. Hence, the Fed accommodates or eases on policy when market fundamentals are going up. In column (9) a more direct measure of productivity is used. The results show that there is some evidence that the Fed lowers interest rate in response to an increase in productivity growth.

In his theoretical model, Smets (1997) agrees with Bernanke and Gertler (1999) that the central bank’s response to unexpected changes in asset prices should depend on how these changes affect the inflation outlook. If they imply a rise in the inflation
forecast, both of these models argue that policy should be tightened and vice versa. However, empirically, Smets (1997) finds that the Bank of Canada eased policy in response to an increase in stock prices. He argues that this can be rationalized if a rise in the stock market reflects positive supply developments which expand output and reduce inflation. He also notes, however, that this could be more of an econometric issue. In particular, he says that the central bank and the stock market could respond to news about underlying inflation that is not captured by the instrument set he used.

Conclusion

This paper has examined how the Fed actually sets its interest rate rule in an environment where stock market volatility and productivity pose an additional concern to policy makers in formulating monetary policy. Indeed, the U.S. economy has experienced a long boom over the past decade and asset prices have escalated to unprecedented levels beginning with the 1983 bull market. These two phenomena make it difficult to clearly isolate stock price bubbles from fundamental values. Without properly identifying each, central bankers will always have a tough time designing optimal monetary policy.

This paper makes a contribution toward this goal. To disentangle irrational exuberance (asset bubbles) from market fundamentals, we use a non-linear model of intrinsic bubbles. Unlike previous studies that use simple proxies for asset price movements, this paper employs a more systematic way to estimate asset price misalignments and fundamental values. Moreover, to explicitly model the volatility in
stock returns, this paper uses an Exponential GARCH model. This model has the property that it can capture volatility asymmetries or leverage effects which are a prominent feature of stock returns.

These estimated measures of market fundamentals, stock price bubbles and stock returns volatility are then used as additional indicator variables in the Fed’s reaction functions. The results suggest that asset price bubbles enter the reaction function with a negative and statistically significant coefficient. However, this result has to be interpreted with caution as some elements of fundamentals might be present in the bubble measure which is essentially an intrinsic bubble driven by dividends. Moreover, the magnitude of the coefficient is too small that its economic significance from a policy perspective is not fully warranted. One important result of the study is that the Fed is seen to accommodate productivity growth and market fundamentals by lowering interest rates. This is indeed an appealing result as existing Taylor rules in the literature are essentially counter-cyclical while this study shows that this ought not be the case. A rise in the fundamental value of stocks is certainly because of strong productivity gains which translate into low future inflationary pressures on the economy and thus the Fed engaging in an expansionary monetary policy seems to be a justifiable action.

In response to an increase in volatility in stock returns, the Fed seems to lower interest rates. The argument is two fold. First, because an increase in volatility brings about a higher level of uncertainty, the Fed eases on policy to restore confidence back. Such a policy was evident in the 1987 stock market crash and the 2001 market dip.
Second, by lowering rates, the Fed injects liquidity in the market and provides an environment that is conducive to investment and growth.
PART V

SUMMARY AND CONCLUSIONS

This dissertation presents three essays to analyze a class of Taylor-based monetary policy rules that forms the basis of contemporary monetary policy decisions. The first essay examines whether Taylor-based monetary policy rules are forward-looking. Unlike previous studies that investigate the forward- or backward-lookingness of policy rules based solely on statistical break tests, this study uses the superexogeneity test and invokes the Lucas critique to help solve the debate. It adopts the methodology that, if the parameters of the Taylor-type rule change when the mechanism generating inflation changes, that is the Lucas critique applies, then inflation is not superexogenous for the parameters of the Taylor rule. In this case where superexogeneity fails, the rule is forward-looking. The analysis is conducted by first estimating a marginal model of the Phillips curve. To capture structural breaks in the inflation process, it uses a heteroskedastic variance model with discrete regime shifts that explains the volatility of inflation. However, although the results indicate that the volatility of inflation reduced by almost 50 percent over the second half of the sample period, we fail to reject the null that inflation is superexogenous to the parameters of the Taylor rule. We fail to reject the null of weak exogeneity, parameter constancy and structural invariance. Overall, there is no sufficient evidence to reject the claim that Taylor-based rules are not forward-looking. If Taylor rules are forward-
looking, it implies that monetary policymakers cannot change the process that determines inflation without affecting the process that determines the Fed Funds rate.

Since superexogeneity tests lack power, the second essay uses a more direct approach to assess which measures of inflation and output are consistent with the Fed Funds rate behavior. The objective is to identify a Taylor-based monetary policy rule that most appropriately characterizes the Fed Funds rate data generating process. The analysis is done for a class of non-nested or rival Taylor rules. The study uses the encompassing principle and performs 116 non-nested P tests to examine their data congruency. Of the various measures of inflation and output gaps that have been traditionally claimed to be relevant for monetary policy design, this study unambiguously comes up with one single measure of inflation and output gaps that best describe the Fed Funds rate behavior. These are the Philadelphia Fed measure of expected inflation as calculated by the Survey of Professional Forecasters and the Congressional Budget Office measure of output gap. Rule recommendations based on these measures alone are consistent with the actual Fed Funds rate over the 1983Q1 to 2002Q2 period. This model is robust and encompasses all other alternative models. This suggests that the model that uses the Philadelphia Fed expected inflation measure and the CBO output gap measure is data congruent.

The third essay uses the results of the second essay to examine how the Fed actually sets its interest rate rule in an environment where stock market volatility and productivity pose an additional concern. Since the U.S. economy has experienced a long boom over the past decade and asset prices have escalated to unprecedented
levels, these two phenomena make it difficult to clearly isolate stock price bubbles from fundamental values. This essay notes that without properly identifying each, central bankers will always have a tough time designing optimal monetary policy. To disentangle irrational exuberance (asset bubbles) from market fundamentals, the study uses a non-linear model of intrinsic bubbles. Unlike previous studies that use simple proxies for asset price movements, this paper employs a more systematic way to estimate asset price misalignments and fundamental values. Moreover, to capture volatility asymmetries or leverage effects which are a prominent feature of stock returns, the study employs an Exponential GARCH model. These estimated measures of market fundamentals, stock price bubbles and stock returns volatility are then used as additional indicator variables in the Fed's reaction functions. The results indicate that the Fed lowers interest rates in response to an increase in stock market volatility. The rationale is that, because an increase in volatility brings about a higher level of uncertainty, the Fed eases on policy to restore confidence back in markets. By lowering rates, the Fed injects liquidity in the market and provides an environment that is conducive to investment and growth. The study also finds evidence that the Fed tends to accommodate productivity gains: it lowers interest rates in response to an increase in productivity growth and an improvement in market fundamentals. This is indeed an appealing result as existing Taylor rules in the literature are essentially counter-cyclical while this study shows that this counter-cyclicality can be dampened when productivity measures are taken into account. A rise in the fundamental values of stocks is certainly because of strong productivity gains which translate into low
future inflationary pressures on the economy and thus the Fed conducting an expansionary monetary policy seems to be a justifiable action. Finally, the study finds that the magnitude of the coefficient of the stock price bubble in the Taylor rule is too small that its economic significance from a policy perspective is not fully warranted. Hence, it can be safely concluded that there is no strong evidence that the Fed responds to asset price bubbles.


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