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Abstract

This paper estimates the US Taylor rule for the period 1997 – 2010, with monthly data, a period characterized by two recessions and asset markets turbulences. Its novelties are that, firstly, we follow Weise and Barbera (2009) and include in the Taylor rule credit spreads (a variable which captures the so-called Minsky Moment) and a modified Wicksellian neutral interest rate. Secondly, we also include a variable to capture the effects of stock price movements. Thirdly, we find that all the variables in the US Taylor rule are I(1) in levels. Therefore, we estimate this equation with the time series methods of unit roots and cointegration, which is perhaps a novelty for the US Taylor rule. We find that there is a well defined cointegrating equation for the US Taylor rule embodying Wicksellian-Minsky effects and stock market movements. Secondly, the Federal Reserve system seems to give relatively a much larger weight to the objective of controlling inflation than to output and unemployment.

Keywords: Taylor rule, Minsky Moment, Wicksellian interest rate, Stock prices, Cointegration

JEL Classification: C22, E52, E58

1. Introduction

Forecasting changes in the central bank interest rate policy is of considerable interest to professional market economists, the media and business. Therefore, there is a large forecasting literature based on surveys, VARS and other quantitative methods. The latter, in particular, estimate the Taylor rule (Taylor, 1993) to model central bank's reaction function in setting the rate of interest, often on a monthly basis. The main explanatory variables in the Taylor rule are the deviations of the inflation rate and output or its growth from their target values, sometimes augmented with a few additional variables to improve the fit.

It is important to distinguish between two different objectives for estimating the Taylor rule.[1] Firstly, as stated at the outset, one may be interested in forecasting whether the central bank will increase or decrease or maintain the bank rate. If a change is expected, then, by how much the rate of interest is likely to change. Secondly, the objective may be only to know how much weight a central bank is giving to the inflation and output deviations from their target values. There may be secondary objectives behind these two main *descriptive* objectives. For example, when the weights for the inflation and output deviations are estimated, these weights may be analyzed to check for consistency with the preferences of the community and the government. US empirical studies generally show that the Federal Reserve (Fed) gives more weight to the objective of stabilizing inflation rate than the European Central Bank (ECB); see Belke and Polleit (2007). On the other hand, if the main objective is to forecast changes in the rate of interest, then, it is necessary to use a forward looking formulation of the Taylor rule and for this purpose it is also necessary to forecast future inflation and output or unemployment rate. Clarida, Gali, and Gertler (2000) have developed such models in which central bank's expected inflation and output (or unemployment rate) replace their current period values. Although different specifications are used for these two purposes, the estimated weights for the US

[1] Another objective in estimating the Taylor rule is to provide the central bank with a simple *prescriptive* rule to implement an optimal monetary policy, using the rate of interest as the monetary policy instrument; see McCallum (1993) and Taylor (1999). Carare and Tchaidze (2005) observed that the scope for the misuse of the Taylor rule is large in the *prescriptive* studies, especially in moderately nonlinear models of the economy. Furthermore, as Svensson (2003) has observed, no central bank has so far made a commitment to a simple instrument rule like the Taylor rule. This is important because central banks can change these so called rules to meet the needs of particular situations and problems. Therefore, the two *descriptive* objectives stated in the text seem to be more appropriate for estimating the Taylor rule.

inflation objective generally exceed three to four times the weight for the output or unemployment objective.

However, as far as we are aware, no systematic attempt has been made to analyze the time series properties of the relevant variables, although there is some recent awareness that some or all variables in the Taylor rule may be non-stationary; see Carare and Tchaidze (2005), Peel et. al., (2004) and Belke and Polleit (2007).[2] In the literature, the Taylor rule is estimated with the classical methods of estimation such as *OLS* or the generalized method of moments (GMM). It is well known that if the variables are non-stationary classical methods underestimate the stand errors and other summary measures. Therefore, the findings in the previous studies may not be entirely reliable and need a reexamination and this is one of the main purposes of our paper. We show that the key variables in the US Taylor rule are non-stationary. Therefore, we reestimate this relationship with the time series methods of cointegration and error correction. Our results indicate that the long run weight given by the Fed to the inflation objective, relative to the weight for output and unemployment objectives, is much higher than the estimates in the existing literature.

In addition, we will analyze the effects of Minsky's insights, known also as the Minsky moment effect and the volatility in the asset markets. According to Minsky's insights (1982), the tolerance of the financial institutions towards risky positions in the asset markets evolves over time during the cyclical phases. During a crisis, the risk perceptions increase, generating a dramatic widening in the credit spreads, measured as the Baa corporate bond yield minus 10-year US Treasury rate. Because the quality of firms' balance sheets depends on the market values of their assets rather than the fundamental values, a bubble in asset prices affects firms' financial positions and, thus, the premiums for external finance. The Fed can respond by reducing interest rates facilitating access to credit. The period between 1998 and 2008 is characterized in the USA by two recessions and asset market turbulences. Therefore, we shall examine with the monthly data how the Fed's interest rate reaction function is influenced by these two factors. Our results indicate that both these effects are significant.

[2] Although Peel et. al., (2004) did not examine the time series properties of the variables in the US Taylor rule, they used a specification which is broadly consistent with the London School of Economics and Hendry's general to specific approach (GETS). The GETS based specifications can overcome the unit root problem in the variables and can be estimated with the usual classical methods. See Rao, Singh and Kumar (2010) for the merits of GETS. However, Vera (2009), using a longer period of about 26 years (1979:9 to 2005:12), finds that inflation and unemployment are stationary at 5% and the rate of interest at the 10% level of significance. In contrast, we found them to be nonstationary in our sample of 1997:7 to 2010:10. Thus these unit root tests seem to be sensitive to the sample size and the lag structures selected, a caveat which we acknowledge.

This paper is organized as follows. Section 2 briefly reviews a few key empirical works on the Taylor rule. Our alternative specifications are discussed in Section 3. Empirical estimates with time series methods are in Section 4. Our results seem to be the first of this kind because the time series properties of the variables have been neglected in the previous studies. Finally, the summary and conclusions of this paper are in Section 5.

2. Literature Review

The *descriptive* variant of the Taylor rule is an important contribution in explaining how a central bank conducts monetary policy. It can be expressed as a simple linear function of current inflation deviation from an inflation target and the output gap.

The original Taylor rule (Taylor, 1993) fits the US data particularly well during the late 1980s and early of 1990s, a period of favorable economic performance. From this hypothetical (not estimated) rule, a vast series of econometric studies is produced to evaluate how central banks have conducted monetary policy. These studies differ in many aspects such as the timing of fundamentals in their use of contemporaneous or expected values of output gap and inflation, functional forms (inclusion of lagged interest rate and/or output and inflation), interest smoothing behavior, choice of additional variables, estimation technique (GMM if the variables are forward looking, or OLS if the specification is backward looking), how the variables are defined and measured (GDP deflator or CPI to measure inflation and different methods of estimating potential output to compute GAP), and sample periods chosen etc.

One of the first developments in the literature consists of incorporating forward looking variables in the original Taylor rule instead of the contemporaneous variables. Clarida, et al. (1998) have used the well known Gali and Gertler (1999) approach to the New Keynesian Phillips curve, in introducing forward looking behavior into the Taylor rule and suggested to use an interest rate smoothing adjustment because of model uncertainty and the need to signal to the public Fed's intention to stabilize the inflation rate. This in turn is expected to affect inflationary expectations and decrease the cost of reducing inflation. Orphanides (2001) suggests using real-time data because they fit well the information set available to the central bank at the time of making policy decisions. However, Ball and Tchaize (2002) showed that that even though results using real-time data may be different, the underlying conclusions of the Taylor rule do not change significantly if a different data set is used. Another issue is concerned with the inclusion of lagged inflation and output gap in the list of the instrument variables. McCallum

(1999) justifies this because it is not possible to know the actual output gap and inflation at the time of setting interest rate.

Some authors have augmented the Taylor rule with additional variables. Botzen and Marey (2010) have estimated a Taylor rule for the European Central Bank (ECB) by adding the stock market price. Their estimates, for period after 1999, show that this is significant in ECB's decisions in setting interest rates. Peel et. al., (2004) find that the lagged changes in the rate of interest and output gap are significant explanatory variables in the Taylor rule.

The two main estimation techniques used in the literature are GMM and OLS. GMM is used when the Taylor rule is forward looking (see for example Clarida et. al., (2000)) and *OLS* is used when it is a backward looking specification; see, for example, Orphanides (2001). As stated in the introduction these classical methods are appropriate if the variables are stationary. However, if these are I(1) in levels, new estimation methods using the time series methods of cointegration and error correction are necessary. The integration order of the variables also depends on the sample period considered. In a long sample period some variables may be stationary and over shorter periods they may all be nonstationary. However, the use of a long sample periods in empirical monetary policy studies has been criticized by Carare and Tchaidze (2005) because central banks often change the parameters of the rules in responses to many factors such as changes in the CEOs, economic events and conditions. They suggest that it is better to focus on a particular period of time which constitutes the scope of the work.

The purpose of this paper is to examine if the Taylor rule is a reasonable representation of US monetary policy during the last 14 years of 1997 to 2010. This period is characterized by two booms and busts due to the internet boom and bust of 1997-2001 and the housing market boom and bust of 2003-2008. Furthermore, during this period of market turbulences all the variables seem to be I(1). This calls for to estimate the Taylor rule with the time series methods.

In light of this brief survey, we restate the purpose of our paper. We follow the intuition of the Weise and Barbera (2009). They have calibrated (not estimated) a Taylor rule for the period starting from 1997 by adding two innovations. The first is to substitute for a constant term of neutral interest rate (used in many studies), with a more volatile term that varies with the Wicksellian interest rate.[3] Their justification is as follows. Long term trajectories vary with economic growth and, therefore, a constant neutral rate makes little sense. The authors calculate the Wicksellian natural rate (r_{wick}) as the five year forward rate ($r5_{fw\_tips}$) and proxy this with the difference between the yields of the 10-year US Treasury note Inflation Protected Securities

[3] A similar approach is used by Clarida (2010).

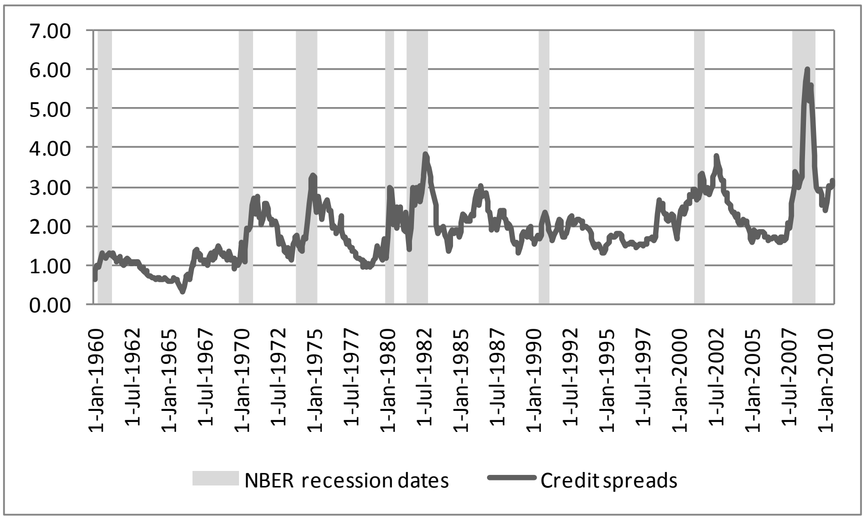
(TIPS) and the 5-year TIPS ($2\left(r10_{tips}\right)-r5_{tips}$), plus the average risk premium (σ) on Baa corporate bonds, implied by the average difference (over the period 1960 – 2010) between Baa corporate bonds minus 10-year US Treasury rate ($\sigma = baa - r10_{tips}$).The original version of the Wicksellian framework did not included the risk component. Weise and Barbera (2009) included the average risk premium for providing a much more realistic description of the last economic events (1990s technology boom and the recent housing boom and bust). Thus, the Wicksell rate is computed as: $r_{wick} = \left(2\left(r10_{tips}\right)-r5_{tips}\right)+(baa - r10_{tips})$.

The second modification consists of adding a term for Minsky moments. The core of Minsky's (1982) insight is the financial fragility. According to this theory, the tolerance towards risky positions in asset markets of the financial institutions evolves over time during the cyclical phases. This influences the financing decisions of firms and their investments. The level of investment in Minsky's model is constrained by the net cash flow generated by a firm's assets and liabilities and its ability to borrow. Firms and lenders behave according to the conventions that guide the optimal ratio of external debt to finance investments. These conventions reflect perceptions of risk. The credit spread ($baas = baa - r10$) reflects changing attitudes towards risk and shifting sentiments. When confidence is high, firms want to use more heavily the external sources of finance for investment and when confidence is low, firms decrease these external sources of finance and investment spending. During a crisis profits and asset prices drop, affecting firms' financial position. Therefore, firms want to reduce the level accumulated debt in the previous phase of the cycle and the risk perceptions increase. This drives up the credit spread and risk premiums as shown below in Figure 1. The increases in the credit spread, also known as baa-spread ($baas$), can clearly be seen during the NBER identified recessions.

Figure 1

Credit spreads

Baa corporate bond rate – US 10-year Treasury rate



3. Specification

With two alternative proxies for the state of the goods market with the deviations of the growth rate of output and unemployment rate, we specify the following six equations. It should be noted that since we shall estimate the long run equation through cointegration, it is not possible to use a commonly used specification in which the lagged interest rate is used as an explanatory variable.[4] However, when we estimate the short run dynamic equations, persistence in the rate of interest will be captured by the coefficient of the lagged error correction term.

Following McCallum (1999), Orphanides and Williams (2003) and Walsh (2004) we use the deviation of the growth rate of output instead of the deviation of the level of output from potential output (GAP) because as noted by Peel et. al., (2004) the Federal Open Market Committee emphasizes the growth in output relative to the growth in potential output, instead of the output gap. Furthermore, this is likely to minimize measurement errors in measuring the

[4] In these commonly used specifications it is assumed that interest rate adjusts to its set rate partially, based on a partial adjustment lag structure. Therefore, the lagged interest rate appears as follows.

$$i_t = (1-\rho)\left[\left(r^* + \pi_t\right) + \beta_\pi\left(\pi_t - \pi^*\right) + \beta_y\left(g_{y_t} - g_y^*\right) + \rho i_{t-1}\right]$$

The meaning of the symbols will be explained shortly.

GAP. Equations (1) and (2) are our basic specifications of the Taylor rule with the two proxies for the goods market conditions and where the depended variable i is the Fed Fund rate (FF).

(1) $$i_t = \left(r^* + \pi_t\right) + \beta_\pi\left(\pi_t - \pi^*\right) + \beta_y\left(g_{y_t} - g_y^*\right) + DUM1 + DUM2 + DUM3$$

(2) $$i_t = \left(r^* + \pi_t\right) + \beta_\pi\left(\pi_t - \pi^*\right) + \beta_u\left(u_t - u^*\right) + DUM1 + DUM2 + DUM3$$

The meaning of the symbols is: $i_t =$ nominal Fed Funds rate; $r^* =$ neutral real fed funds rate = $\left(r_{wick} - \sigma - \tau\right)$; $r_{wick} =$ Wicksellian natural rate = $\left(2r10_{tips} - r5_{tips}\right) + \sigma$; $\tau =$ average term premium $(r10_{tips} - i)$, over the period 1960-2010; $\pi_t =$ year over year core CPI inflation rate; $\pi^* =$ target inflation rate = 2; $g_{yt} =$ growth rate of year over year industrial production index (IP); $g_y^* =$ average IP growth rate during 1960-2010 = 2.91; DUM1 = dummy variable taking a value of 1 during 2001:10-2002:8 and zero in all other periods; DUM2 = dummy variable taking a value of 1 during 2004:3-2005:3 and zero in all other periods; DUM3 = dummy taking a value of 1 during 2008:11-2009:4 and zero in all other periods; $u =$ unemployment rate and $u^* =$ natural unemployment rate = 5[5]. The definitions and sources of data are in the data appendix.

Weise and Barbera (2009) refer to a measure of risk-free neutral interest rate. For this purpose, they subtract two average spread terms from the Wicksellian natural rate: the average credit spread (σ) and the average term spread (τ). This last one adjusts the rate for the fact that the yield curve, historically, exhibits a positive slope. However, in our case these two adjustments do not matter because they enter in the estimation as constants and do not influence the results. Three dummy variables are included in the long-run relationship. DUM1 and DUM2 represent, respectively, the effects of the well known internet busts and high level in oil and energy prices in period 2004-2005 (around $70 a barrel) which pushes Fed to maintain a smooth low level of fed funds despite the recovery in stock market for a fear of stagflation (low growth and high inflation). Both dummy variables are expected to have negative coefficients. DUM3 represents the period in which Fed drops the fed funds at a value near to zero (maintaining until

[5] The natural rate of unemployment changes over time. In the U.S., some mainstream economists have placed the natural rate of unemployment in the 5% to 6% range, though a few others think that it was lower (4%) or higher (7%). This variability and lack of precision in the natural rate of unemployment does not change our results because it enters as a constant in our estimations.

now a flat value close to zero), whereas in absence of a natural constraint to being negative the fair value should suggest a large negative value (see for example Rudebusch 2010).

In equation (1) it is assumed that the Fed has a preferred neutral rate of interest (r^*), which if maintained has no effect on the rates of inflation (π) and output growth (g_y). However, this neutral rate is fully adjusted to the rate of inflation and it is computed as an adjusted Wicksellian natural rate. The details are shown above.

π^* and g_y^* are the target rate of inflation, assumed to be 2%, and target growth rate of output, assumed to be its average growth rate of 2.91% during 1960 and 2009. Three dummy variables are added to capture different types of stock market volatility, which is explained above. Thus the main purpose of estimating this equation is to examine how well this basic specification captures the Fed's decisions to adjust the Fed Fund rate and what are the implicit weights attached to the inflation and output targets viz., β_π and β_y, respectively. Equation (2) is the same as (1) but the goods market condition is proxied with the deviation of the unemployment rate (u) from its natural rate (u^*).

We enter the Minsky moments into the Taylor rule, through the credit spread. In equations (3) and (4) the Minsky effect is introduced through $(baas - \sigma)$. The Fed is supposed to respond to risk premium shock, the difference between credit spread (baas) and its average (σ). And in equations (5) and (6) stock market volatility is added through $(sp500 - sp500^*)$.

(3) $$\begin{aligned} i_t = \left(r^* + \pi_t\right) + \beta_\pi\left(\pi_t - \pi^*\right) + \beta_y\left(g_{y_t} - g_y^*\right) + \beta_{baas}\left(baas_t - \sigma\right) \\ + DUM1 + DUM2 + DUM3 \end{aligned}$$

(4) $$\begin{aligned} i_t = \left(r^* + \pi_t\right) + \beta_\pi\left(\pi_t - \pi^*\right) + \beta_u\left(u_t - u^*\right) + \beta_{baas}\left(baas_t - \sigma\right) \\ + DUM1 + DUM2 + DUM3 \end{aligned}$$

(5) $$\begin{aligned} i_t = \left(r^* + \pi_t\right) + \beta_\pi\left(\pi_t - \pi^*\right) + \beta_y\left(g_{y_t} - g_y^*\right) + \beta_{baas}\left(baas_t - \sigma\right) \\ + \beta_{sp}\left(sp500_t - sp500^*\right) + DUM1 + DUM2 + DUM3 \end{aligned}$$

(6) $$\begin{aligned} i_t = \left(r^* + \pi_t\right) + \beta_\pi\left(\pi_t - \pi^*\right) + \beta_u\left(u_t - u^*\right) + \beta_{baas}\left(baas_t - \sigma\right) \\ + \beta_{sp}\left(sp500_t - sp500^*\right) + DUM1 + DUM2 + DUM3 \end{aligned}$$

The new symbols in equations (3) to (6) have the following meanings.

$baas = baa - r10$; σ = average risk premium (average baas, for period 1960 – 2010);

sp500 = S&P 500 index; $sp500^*$ = average value of S&P 500 index during 1997-2010;

A rationale for monetary policy to react to stock prices is that the collapse of a stock market can result in a financial crisis, as well as a sharp contraction in economic activity. Minsky's theory about financial fragility explains how an economy passes from a robust financial structure to a fragile structure. Stabilizing stock prices could be optimal in cases of strong turbulences of asset markets[6]. A rise in the credit spread above its historically average, measured as $(baas - \sigma)$, is a signal of instability in the financial markets. Data of GDP growth are not available for monthly frequencies. Therefore g_y is measured as the growth rate in industrial output. In addition we consider growth rate instead of a gap measure, because in this way we bypass the problem of calculating the potential output, which has been controversial and debated in the literature without a satisfactory resolution.

An important aspect in this paper is the use of cointegration technique. Previous studies assumed that all the variables are I(0) and used classical estimation methods. In Table 1 we implement two unit roots tests viz., the ADF test and the Elliot-Rothemberg-Stock DF-GLS unit root test. In particular, it is well known that the last one performs fairly well in small samples. As we can see from the ADF test and the DF-GLS test, reported below, all variables are I(1) in their levels. This is also intuitive because our sample period (1997:7-2010:10) is a period characterized by strong turbulences in the economy.

Table 1

Unit Root Tests

	1997:7 – 2010:10	
	ADF	**DF-GLS**
i	-1.315	-0.525
Δi	-5.389**	-5.375**
$baas$	-2.74	-1.854
$\Delta baas$	-7.566**	-7.522**
π	-0.291	0.493
$\Delta \pi$	-4.861**	-4.821**

[6] For a complete explanation of why central bank should respond to stock prices movements see Botzen and Marey (2010).

g_y	-1.256	-0.427
Δg_y	-7.123**	-3.168**
r^*	-0.612	-0.057
Δr^*	-13.77**	-12.511**
$sp500$	-2.341	-1.063
$\Delta sp500$	-9.928**	-5.798**
u	-0.553	-0.560
Δu	-3.760**	-3.683**

**Significant at the 1% level;

*Significant at the 5% level.

Since that all variables are I(1) for period considered (1997:7-2010:10), we can use cointegration technique to estimate the long run determinants of the rate of interest. Three estimation techniques are implemented viz., FMOLS (Fully modified OLS), CCR (Canonical cointegration regression), DOLS (Dynamic ordinary least squares).

These estimators deal with the problem of second-order asymptotic bias arising from serial correlation and endogeneity and they are asymptotically equivalent and efficient. In particular, DOLS provides reliable and robust estimates in small sample sizes (see for example Inder (1993)). However, the use of more than one estimator is crucial if there is concern about the robustness of the results. The *p*-values of the coefficients are reported in the square brackets below the coefficients. Estimates of equations (1) and (2) are in Tables 2 and 3 respectively.

Table 2. Estimation of Version 1

$$i_t = \left(r^* + \pi_t\right) + \beta_\pi\left(\pi_t - \pi^*\right) + \beta_y\left(g_{y_t} - g_y^*\right) + DUM1 + DUM2 + DUM3$$

	FMOLS	CCR	DOLS
$r^* + \pi$	0.606	0.604	0.415
	[0.00]	[0.00]	[0.00]
$\pi - \pi^*$	2.402	2.397	2.845
	[0.00]	[0.00]	[0.00]
$g_y - g_y^*$	0.208	0.209	0.253
	[0.00]	[0.00]	[0.00]
C	-0.090	-0.079	1.143
	[0.93]	[0.94]	[0.21]

DUM1	-2.328	-2.310	-2.323
	[0.00]	[0.00]	[0.00]
DUM2	-1.645	-1.633	-1.660
	[0.00]	[0.00]	[0.00]
DUM3	0.720	0.746	0.437
	[0.33]	[0.32]	[0.30]
EG residual test		-4.005	
		[0.32]	

Notes: Time period 1997:7 – 2010:10. *p*-values are in squares brackets. FMOLS = Fully modified OLS; CCR = Canonical cointegrating regression; DOLS = Dynamic OLS; EG = Engle-Granger t-test for cointegration. FMOLS and CCR use Newey-West automatic bandwidth selection, usually $n^{(1/3)}$ where n is the number of observations, in computing the long-run variance matrix. In the DOLS estimation, leads and lags are selected according to HQ criteria. The standard errors for DOLS estimation are calculated using the Newey-West correction.

Table 3. Estimation of Version 2

$$i_t = \left(r^* + \pi_t\right) + \beta_\pi\left(\pi_t - \pi^*\right) + \beta_u\left(u_t - u^*\right)$$
$$+ DUM1 + DUM2 + DUM3$$

	FMOLS	CCR	DOLS
$r^* + \pi$	0.516	0.519	0.505
	[0.01]	[0.01]	[0.01]
$\pi - \pi^*$	1.287	1.276	2.529
	[0.03]	[0.03]	[0.00]
$u - u^*$	-0.476	-0.478	-0.272
	[0.01]	[0.01]	[0.07]
C	0.652	0.633	0.553
	[0.69]	[0.70]	[0.63]
DUM1	-2.902	-2.918	-2.887
	[0.00]	[0.00]	[0.00]
DUM2	-1.688	-1.641	-1.501
	[0.01]	[0.01]	[0.00]
DUM3	-1.370	-1.366	0.756
	[0.15]	[0.15]	[0.12]
EG residual test		-2.662	
		[0.90]	

Notes: See notes for Table 2.

All the long run coefficients in Tables 2 are significant at the 1% level except DUM3. In Table 3 important long run coefficients are also significant at the 1% level with the exception of the coefficients for DUM3, the intercept and the deviation of the unemployment rate with DOLS estimate. The coefficient for the latter, however, is significant at the 10% level. But most importantly, both versions do not pass the cointegrating residual test (Engle-Granger residual test).

In the following we present estimates of the other four specifications in Tables 4 to 7. In Tables 4 and 5, estimates with the Minsky effect are given and in Tables 6 and 7, estimates with the Minsky effect and stock market volatility are given.

Table 4. Estimation of Version 3

$$i_t = \left(r^* + \pi_t\right) + \beta_\pi\left(\pi_t - \pi^*\right) + \beta_y\left(g_{y_t} - g_y^*\right) + \beta_{baas}\left(baas_t - \sigma\right) + DUM1 + DUM2 + DUM3$$

	FMOLS	CCR	DOLS
$r^* + \pi$	0.813	0.813	0.765
	[0.00]	[0.00]	[0.00]
$\pi - \pi^*$	1.562	1.564	1.791
	[0.00]	[0.00]	[0.00]
$g_y - g_y^*$	0.086	0.085	0.064
	[0.00]	[0.00]	[0.16]
$baas - \sigma$	-1.154	-1.171	-1.091
	[0.00]	[0.00]	[0.00]
C	-0.829	-0.823	-0.583
	[0.13]	[0.13]	[0.48]
DUM1	-2.104	-2.089	-2.092
	[0.00]	[0.00]	[0.00]
DUM2	-1.778	-1.779	-1.904
	[0.00]	[0.00]	[0.00]
DUM3	2.889	2.988	1.861
	[0.00]	[0.00]	[0.00]
EG residual test		-4.934	

	[0.06]

Notes: See notes for Table 2.

Table 5. Estimation of Version 4

$$i_t = \left(r^* + \pi_t\right) + \beta_\pi\left(\pi_t - \pi^*\right) + \beta_u\left(u_t - u^*\right) + \beta_{baas}\left(baas_t - \sigma\right) + DUM1 + DUM2 + DUM3$$

	FMOLS	CCR	DOLS
$r^* + \pi$	0.785	0.798	0.785
	[0.00]	[0.00]	[0.00]
$\pi - \pi^*$	1.092	1.091	1.064
	[0.00]	[0.00]	[0.00]
$u - u^*$	-0.172	-0.156	-0.212
	[0.07]	[0.10]	[0.05]
$baas - \sigma$	-1.307	-1.357	-1.236
	[0.00]	[0.00]	[0.00]
C	-0.599	-0.668	-0.528
	[0.46]	[0.42]	[0.57]
DUM1	-2.011	-1.991	-2.197
	[0.00]	[0.00]	[0.00]
DUM2	-1.786	-1.772	-1.862
	[0.00]	[0.00]	[0.00]
DUM3	3.661	3.876	2.072
	[0.00]	[0.00]	[0.00]
EG residual test		-4.058	
		[0.27]	

Notes: See notes for Table 2.

Again, specification 3 presents all the coefficients with expected signs and statistically significant, whereas specification 4 presents a coefficient for unemployment rate only significant at the 10%. Like the first two versions, both specification 3 and 4 do not pass the cointegrating residual test.

Table 6. Estimation of Version 5

$$i_t = \left(r^* + \pi_t\right) + \beta_\pi\left(\pi_t - \pi^*\right) + \beta_y\left(g_{y_t} - g_y^*\right) + \beta_{baas}\left(baas_t - \sigma\right)$$
$$+ \beta_{sp}\left(sp500_t - sp500^*\right) + DUM1 + DUM2 + DUM3$$

	FMOLS	**CCR**	**DOLS**
$r^* + \pi$	0.793	0.792	0.727
	[0.00]	[0.00]	[0.00]
$\pi - \pi^*$	1.341	1.333	1.520
	[0.00]	[0.00]	[0.00]
$g_y - g_y^*$	0.091	0.090	0.107
	[0.00]	[0.00]	[0.02]
$baas - \sigma$	-1.101	-1.036	-0.816
	[0.00]	[0.00]	[0.00]
$sp500 - sp500^*$	0.002	0.002	0.002
	[0.00]	[0.00]	[0.00]
C	-3.044	-3.038	-3.012
	[0.00]	[0.00]	[0.00]
DUM1	-1.585	-1.560	-1.740
	[0.00]	[0.00]	[0.00]
DUM2	-1.671	-1.674	-1.707
	[0.00]	[0.00]	[0.00]
DUM3	3.263	3.374	1.937
	[0.00]	[0.00]	[0.00]
EG residual test		-5.634	
		[0.02]	
λ		-0.115	
		[0.00]	
DW test		2.072	
JB test		3.303	
		[0.19]	
BPG test		0.921	
		[0.64]	

Notes: See notes for Table 2. λ, factor loading in the ECM; DW, Durbin-Watson test for serial autocorrelation; JB, Jarque-Bera normality test; BPG, Breusch-Pagan-Godfrey test. FMOLS and CCR use Newey-West automatic bandwidth selection in computing the long-run variance matrix. In the DOLS estimation, leads and lags are selected according to HQ criteria. The standard errors for DOLS estimation are calculated using the Newey-West correction.

Four impulse dummies are inserted in ECM estimation for capturing outliers during recession periods of 2001 and 2008 (details are in technical appendix)

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Table 7. Estimation of Version 6

$$i_t = \left(r^* + \pi_t\right) + \beta_\pi\left(\pi_t - \pi^*\right) + \beta_u\left(u_t - u^*\right) + \beta_{baas}\left(baas_t - \sigma\right)$$
$$+ \beta_{sp}\left(sp500_t - sp500^*\right) + DUM1 + DUM2 + DUM3$$

	FMOLS	CCR	DOLS
$r^* + \pi$	0.839	0.844	0.812
	[0.00]	[0.00]	[0.00]
$\pi - \pi^*$	0.845	0.852	0.881
	[0.00]	[0.00]	[0.00]
$u - u^*$	-0.145	-0.141	-0.182
	[0.06]	[0.08]	[0.08]
$baas - \sigma$	-1.238	-1.264	-1.128
	[0.00]	[0.00]	[0.00]
$sp500 - sp500^*$	0.002	0.002	0.002
	[0.00]	[0.00]	[0.01]
C	-2.804	-2.852	-2.670
	[0.00]	[0.00]	[0.00]
DUM1	-1.902	-1.889	-2.005
	[0.00]	[0.00]	[0.00]
DUM2	-1.693	-1.673	-1.718
	[0.00]	[0.00]	[0.00]
DUM3	3.385	3.538	2.259
	[0.00]	[0.00]	[0.00]
EG residual test		-4.678	
		[0.17]	

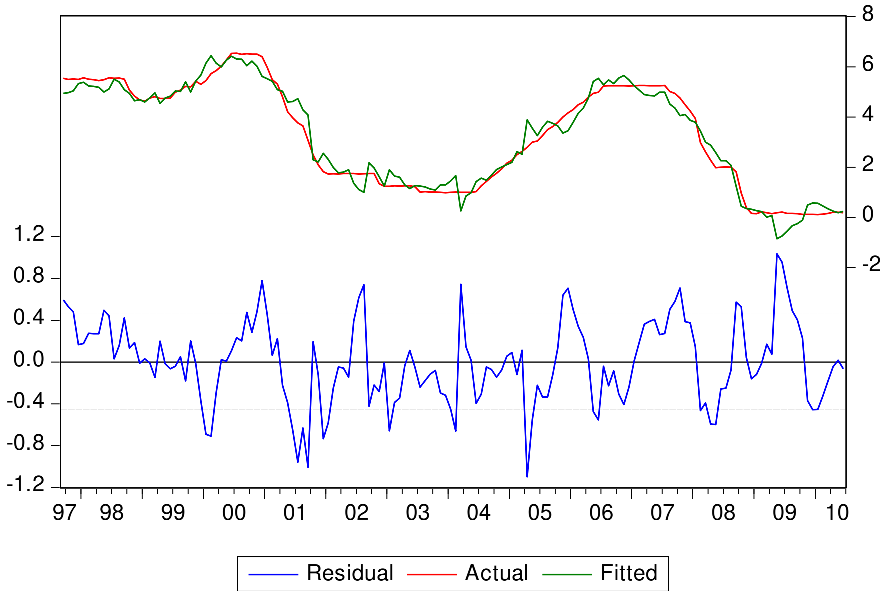
Notes: See notes for Table 2.

The results of tables 2-7 show that the version 5 of Taylor rule (the augmented Taylor rule with risk spread and stock prices) is the only version which passes the EG test. All the estimation methods (DOLS, FMOL, and CCR) show very similar results in terms of coefficients, the residual cointegration test is statistically significant at 5%, and ECM (in terms of factor loading and residual tests) is satisfactory. Figure 1 shows the fitted of the long-run estimation of version 5. As we can see graphically, the fit of fed funds rate is very impressive. Estimates of the short run dynamic equation, based on the above DOLS for version 5 with the lagged ECM, are given in Table 1A in the Technical appendix. Figure 2 is based on this dynamic version.

Figure 2

Based on the Dynamic Version of Model 5

(shown in the Appendix)



Since the theory on the Minsky-Wicksell-modified Taylor rule (Barbera and Weise (2009)) suggests that the coefficients of $\left(r^{*} + \pi\right) = 1$ and $(\text{baas} - \sigma) = -1$, we used the Wald test to verify if these restrictions are valid. These joint restrictions are accepted with a *p*-value of .07. We then estimate the version 5 with these restrictions and the results are in Table 8. This is an important result, which confirms the theoretical construction of the model.

The estimated weights in Table 6 and Table 8 show that the weights given to the inflation target by the Fed are about 10 to 12 times higher than the weight for output. This may be because we have used the industrial production index in the specification of the Taylor rule, and not the GDP. Furthermore, the coefficients of both the Minsky effect and stock market volatility have significant and the expected effects on the Fed’s reaction function.

Table 8. Estimation of Version 5 with Restrictions

$$\left[i_t+\left(baas_t-\sigma\right)-\left(r_t^*+\pi_t\right)\right]=\beta_\pi\left(\pi_t-\pi^*\right)+\beta_y\left(g_{y_t}-g_y^*\right)+\beta_{sp}\left(sp500_t-sp500^*\right)+DUM1+DUM2+DUM3$$

	FMOLS	CCR	DOLS
$r^*+\pi$	1	1	1
	-	-	-
$\pi-\pi^*$	0.969	0.964	0.937
	[0.00]	[0.00]	[0.00]
$g_y-g_y^*$	0.083	0.084	0.069
	[0.00]	[0.00]	[0.03]
$baas-\sigma$	-1	-1	-1
	-	-	-
$sp500-sp500^*$	0.002	0.002	0.002
	[0.00]	[0.00]	[0.00]
C	-4.473	-4.478	-4.233
	[0.00]	[0.00]	[0.00]
DUM1	-1.692	-1.669	-1.870
	[0.00]	[0.00]	[0.00]
DUM2	-1.545	-1.543	-1.505
	[0.00]	[0.00]	[0.00]
DUM3	3.235	3.272	2.283
	[0.00]	[0.00]	[0.00]
EG residual test		-5.490	
		[0.01]	
λ		-0.214	
		[0.00]	
DW test		2.021	
JB test		2.525	
		[0.28]	
BPG test		1.477	
		[0.19]	

Notes: See notes for Table 2. λ, factor loading in the ECM; DW, Durbin-Watson test for serial autocorrelation; JB, Jarque-Bera normality test; BPG, Breusch-Pagan-Godfrey test. FMOLS and CCR use Newey-West automatic bandwidth selection in computing the long-run variance matrix. In the DOLS estimation, leads and lags are selected according to HQ criteria. The standard errors for DOLS estimation are calculated using the Newey-West correction.

5. Conclusions

In this paper we estimated an extended US Taylor rule with the time series methods and found that there is a well defined cointegration equation between the Fed Fund rate and its determinants. We have used monthly data from 1997:7 to 2010:10. U.S. monetary policy in this period is characterized by two recessions and large asset markets turbulences.

Our extensions to the Taylor equation are as follows. Firstly, the neutral rate of interest is adjusted for the Wicksell effect; secondly, the Minsky moment effect is added and thirdly, the turbulence in the stock market is introduced. The first two modifications are due to analytical work by Weise and Barbera (2009). Since they did not estimate this equation with their modifications, our estimates fill an important gap and validated their theoretical insights. All the three modifications are found to have significant and expected effects on Fed's reaction function. Thus, the Fed is found to react not only to the standard objectives of stabilizing inflation, output or unemployment but also adjust the interest rate by taking into account stock market conditions and the changes in the Minsky moment, proxied with the credit spread. The Fed increases the interest rate when the stock prices are above the average and decreases the interest rate when credit spread increases during the recessions; see Table 6 and Figure 2. It is also noteworthy that our estimate of the short run dynamic equation (see Table 1A in the appendix) explains as much as 80% variation in the Fed's interest rate reaction function. The lagged error correction term has an expected negative and significant coefficient and implies that interest rate rule in the USA is highly persistent and is about 0.89. These are close to recent estimates by Belke and Polleit (2007); see their Table 2.

However, our estimates of the weights given by the Fed to inflation and output (or unemployment) objectives are much different from the estimates in the existing literature. While the weight given to inflation objective is about three to four times larger in the existing studies, we found that the weight for the inflation is ten to twelve times larger. This may partly be due to our measure of output with industrial production instead of GDP and/or due to our method of estimation using time series methods. Recently Vera (2009) found that use of industrial output, instead of GDP, gives a better explanation of the Fed's reaction function. However, variations in the rate of growth of industrial production will be much higher than its counterpart with the GDP. For example, the maximum and minimum growth rates (expressed as year over year) of industrial production are, respectively, 8.68% and -12.86% during our sample period. In contrast the range for variation in the growth rate of GDP is only 5.37% and -4.10%.[7] Besides this, there are other possibilities. Instead of using the difference between the levels of actual and potential output, we have used the difference between the growth rates of output. It is also possible that Fed's main objective is to ensure a low rate of inflation even if this needs a substantial slowdown in the rate of growth of output and a higher unemployment rate.

Finally, a limitation in our paper is that we did not use explicitly an instrumental variable option to minimize endogenous variable biases, but depended on the DOLS method of estimation, which is found by Inder (1993) and Montalvo (1995) to minimize these biases. We hope that other researchers on the Taylor rule will use our paper as an example to use time series methods of estimation instead of the standard classical methods and make further improvements to the specification.

[7] Although it is not a valid argument, the range of variation in the industrial output is about 2.5 times more than in the GDP. Therefore, the weight for the rate of growth of industrial production is likely to be considerably less when it is used as a proxy for the rate of growth in the GDP. Since there are no monthly data on GDP, its range is computed with the quarterly data.

Technical Appendix

The error correction model is obtained in two steps. In the first step we calculated the residuals from the DOLS estimates of the run relationship of Model 5 in Table 6. Incorporating the lagged residuals (ECT_{t-1}), the short run error correction dynamic model is estimated with 12 lagged changes of the variables. The coefficient of ECT_{t-1} has the correct negative sign and significant. It implies that about 11% of the adjustment towards equilibrium takes place in one month and also implies that the so called interest rate smoothing coefficient is about 0.89.

We also estimated the ECM based model for the restricted version of Model 5 and to conserve space this is not reported.

Table A1. Error correction model of version 5.

$$\Delta i_t = Const + \lambda ECT_{t-1} + \sum_{j=1}^{n}\gamma_{1,j}\Delta i_{t-j} + \sum_{j=1}^{n}\gamma_{2,j}\Delta\left(r^*_{t-j} + \pi_{t-j}\right) + \sum_{j=1}^{n}\gamma_{3,j}\Delta\left(\pi_{t-j} - \pi^*\right)$$
$$+\sum_{j=1}^{n}\gamma_{4,j}\Delta\left(g_{y_{t-j}} - g^*_y\right) + \sum_{j=1}^{n}\gamma_{4,j}\Delta\left(baas_{t-j} - \sigma\right) + \sum_{j=1}^{n}\gamma_{5,j}\Delta\left(sp500_{t-j} - sp500^*\right)$$

Variable	Coefficient	Std. Error	t-Statistic	Prob.
ECT_{t-1}	-0.114497	0.025629	-4.467561	0
C	-0.000615	0.010322	-0.059617	0.9526
Δi_{t-1}	0.321273	0.081893	3.923083	0.0002
$\Delta\left(r^*_{t-1} + \pi_{t-1}\right)$	0.072604	0.075653	0.959695	0.3406
$\Delta\left(\pi_{t-1} - \pi^*\right)$	-0.090003	0.084939	-1.059622	0.293
$\Delta\left(g_{y_{t-1}} - g^*_y\right)$	0.002279	0.085037	0.026802	0.9787
$\Delta\left(baas_{t-1} - \sigma\right)$	-0.027461	0.014546	-1.887852	0.0633
$\Delta\left(sp500_{t-1} - sp500^*\right)$	0.000122	0.000314	0.387843	0.6993
Δi_{t-2}	0.242095	0.090734	2.66817	0.0095
$\Delta\left(r^*_{t-2} + \pi_{t-2}\right)$	-0.094481	0.076076	-1.241935	0.2185
$\Delta\left(\pi_{t-2} - \pi^*\right)$	0.136755	0.087138	1.569407	0.1211
$\Delta\left(g_{y_{t-2}} - g^*_y\right)$	0.04211	0.081536	0.516459	0.6072
$\Delta\left(baas_{t-2} - \sigma\right)$	-0.019254	0.014378	-1.339123	0.1849
$\Delta\left(sp500_{t-2} - sp500^*\right)$	0.000871	0.000317	2.744284	0.0077
Δi_{t-3}	0.224846	0.084926	2.647567	0.01
$\Delta\left(r^*_{t-3} + \pi_{t-3}\right)$	0.12193	0.077322	1.576903	0.1194

$\Delta\left(\pi_{t-3}-\pi^*\right)$	0.169532	0.085093	1.992314	0.0503
$\Delta\left(g_{y_{t-3}}-g_y^*\right)$	0.120017	0.082668	1.451796	0.1511
$\Delta\left(baas_{t-3}-\sigma\right)$	0.00326	0.014068	0.231698	0.8175
$\Delta\left(sp500_{t-3}-sp500^*\right)$	0.000392	0.000313	1.251952	0.2148
Δi_{t-4}	0.075971	0.087386	0.869372	0.3877
$\Delta\left(r_{t-4}^*+\pi_{t-4}\right)$	0.161725	0.083664	1.933044	0.0573
$\Delta\left(\pi_{t-4}-\pi^*\right)$	0.126271	0.084372	1.496597	0.1391
$\Delta\left(g_{y_{t-4}}-g_y^*\right)$	0.056174	0.081159	0.692143	0.4912
$\Delta\left(baas_{t-4}-\sigma\right)$	0.032363	0.013703	2.361691	0.021
$\Delta\left(sp500_{t-4}-sp500^*\right)$	0.000296	0.000327	0.905131	0.3685
Δi_{t-5}	0.02558	0.088911	0.287704	0.7744
$\Delta\left(r_{t-5}^*+\pi_{t-5}\right)$	-0.060066	0.081049	-0.741111	0.4611
$\Delta\left(\pi_{t-5}-\pi^*\right)$	-0.012769	0.080399	-0.158819	0.8743
$\Delta\left(g_{y_{t-5}}-g_y^*\right)$	-0.070118	0.079815	-0.878511	0.3827
$\Delta\left(baas_{t-5}-\sigma\right)$	0.012683	0.014082	0.900623	0.3709
$\Delta\left(sp500_{t-5}-sp500^*\right)$	-0.000265	0.000318	-0.832934	0.4078
Δi_{t-6}	0.078479	0.087872	0.893101	0.3749
$\Delta\left(r_{t-6}^*+\pi_{t-6}\right)$	-0.02494	0.083068	-0.300238	0.7649
$\Delta\left(\pi_{t-6}-\pi^*\right)$	-0.005783	0.078784	-0.073398	0.9417
$\Delta\left(g_{y_{t-6}}-g_y^*\right)$	-0.069155	0.078516	-0.880774	0.3815
$\Delta\left(baas_{t-6}-\sigma\right)$	0.020667	0.01453	1.422303	0.1594
$\Delta\left(sp500_{t-6}-sp500^*\right)$	-0.000173	0.000291	-0.593088	0.5551
Δi_{t-7}	0.12527	0.092557	1.353443	0.1803
$\Delta\left(r_{t-7}^*+\pi_{t-7}\right)$	-0.203277	0.081798	-2.485113	0.0154
$\Delta\left(\pi_{t-7}-\pi^*\right)$	0.207724	0.076498	2.715408	0.0084
$\Delta\left(g_{y_{t-7}}-g_y^*\right)$	-0.027265	0.076555	-0.356146	0.7228
$\Delta\left(baas_{t-7}-\sigma\right)$	0.024064	0.014516	1.657741	0.1019
$\Delta\left(sp500_{t-7}-sp500^*\right)$	-4.90E-05	0.00029	-0.169188	0.8661
Δi_{t-8}	-0.006629	0.105739	-0.062693	0.9502
$\Delta\left(r_{t-8}^*+\pi_{t-8}\right)$	-0.134516	0.084351	-1.594714	0.1153
$\Delta\left(\pi_{t-8}-\pi^*\right)$	0.001602	0.08042	0.019926	0.9842
$\Delta\left(g_{y_{t-8}}-g_y^*\right)$	-0.041497	0.081465	-0.509384	0.6121
$\Delta\left(baas_{t-8}-\sigma\right)$	-0.030531	0.013745	-2.221162	0.0296

$\Delta\left(sp500_{t-8}-sp500^{*}\right)$	0.000105	0.000277	0.377104	0.7073
Δi_{t-9}	-0.112428	0.099924	-1.125133	0.2644
$\Delta\left(r_{t-9}^{*}+\pi_{t-9}\right)$	-0.240771	0.085151	-2.82756	0.0061
$\Delta\left(\pi_{t-9}-\pi^{*}\right)$	-0.079841	0.079686	-1.001941	0.3199
$\Delta\left(g_{y_{t-9}}-g_{y}^{*}\right)$	0.105848	0.08325	1.271443	0.2078
$\Delta\left(baas_{t-9}-\sigma\right)$	-0.017676	0.013349	-1.324069	0.1898
$\Delta\left(sp500_{t-9}-sp500^{*}\right)$	-0.000669	0.000285	-2.34551	0.0219
Δi_{t-10}	-0.136915	0.098006	-1.397004	0.1669
$\Delta\left(r_{t-10}^{*}+\pi_{t-10}\right)$	-0.117386	0.082681	-1.419741	0.1602
$\Delta\left(\pi_{t-10}-\pi^{*}\right)$	0.016664	0.07661	0.217515	0.8284
$\Delta\left(g_{y_{t-10}}-g_{y}^{*}\right)$	-0.091026	0.085009	-1.070788	0.288
$\Delta\left(baas_{t-10}-\sigma\right)$	-0.010623	0.01383	-0.768092	0.4451
$\Delta\left(sp500_{t-10}-sp500^{*}\right)$	5.31E-05	0.000295	0.180239	0.8575
Δi_{t-11}	-0.16705	0.09546	-1.74995	0.0846
$\Delta\left(r_{t-11}^{*}+\pi_{t-11}\right)$	-0.02451	0.080553	-0.304275	0.7618
$\Delta\left(\pi_{t-11}-\pi^{*}\right)$	0.061686	0.080439	0.766858	0.4458
$\Delta\left(g_{y_{t-11}}-g_{y}^{*}\right)$	-0.015066	0.085112	-0.177018	0.86
$\Delta\left(baas_{t-11}-\sigma\right)$	-0.003501	0.013517	-0.259031	0.7964
$\Delta\left(sp500_{t-11}-sp500^{*}\right)$	-0.000156	0.0003	-0.518733	0.6056
Δi_{t-12}	0.122035	0.08594	1.419996	0.1601
$\Delta\left(r_{t-12}^{*}+\pi_{t-12}\right)$	0.052707	0.071246	0.739789	0.4619
$\Delta\left(\pi_{t-12}-\pi^{*}\right)$	0.059492	0.071474	0.832362	0.4081
$\Delta\left(g_{y_{t-12}}-g_{y}^{*}\right)$	-0.119432	0.085486	-1.397089	0.1669
$\Delta\left(baas_{t-12}-\sigma\right)$	-0.005704	0.013881	-0.410951	0.6824
$\Delta\left(sp500_{t-12}-sp500^{*}\right)$	0.000546	0.000304	1.796076	0.0769
DUM2008M10	-1.135089	0.155784	-7.286289	0
DUM2008M2	-0.655937	0.130831	-5.013626	0
DUM2002M11	-0.499403	0.131385	-3.801074	0.0003
DUM2001M9	-0.36574	0.095599	-3.825765	0.0003
Adjust. R^2	0.789246			
DW stat.	2.072591			
JB test	Value	3.303354	Prob.	0.1917
BPG test	Value	0.920638	Prob.	0.6391

Notes: λ, factor loading in the ECM; DW, Durbin-Watson test for serial autocorrelation; JB, Jarque-Bera normality test; BPG, Breusch-Pagan-Godfrey test for heteroskedasticity**.** The lag length is selected in a way to make the error term as much white noise as possible. Four impulse dummy variables are added. DUM2001M9 represents the two towers attack; DUM2002M11 represents the drops in interest rates (after the increase in early 2002) by Fed after the faltering in US recovery in the fall 2002; DUM2008M2 represents the financial crisis of Bear Sterns which will collapse after some weeks; DUM2008M10 is the peak of financial institutions crisis (Lehmann Brothers, Merrill Lynch, Fannie Mae, Freddie Mac, etc.).

Data Appendix

All data are taken from Federal Reserve Economic Data (FRED):

http://research.stlouisfed.org/fred2/

$i_t =$ fed funds rate.

$\sigma =$ Average risk premium = Baa corporate bond – 10-year US Treasury rate, for period 1960 – 2010.

$r_{wick} =$ Wicksellian natural rate = 2(10-year US Treasury TIPS yields) – 5-year US Treasury TIPS yields + σ

$baas =$ Baa corporate bond rate – 10-year Treasury rate.

$\tau =$ average term premium = 10-year US Treasury rate – *i*, 1960-2010.

$r_t^* =$ neutral real fed funds rate $= r_{wick} - \sigma - \tau$.

$\pi =$ year-over-year core CPI rate.

$\pi^* =$ target inflation rate = 2.

$g_y =$ year over year industrial production index (IP) growth rate.

$g_y^* =$ average IP growth rate, 1960-2010 = 2.91

$u =$ rate of unemployment.

$u^* =$ natural rate of unemployment = 5.

$sp500 =$ S&P 500 index.

$sp500^* =$ average value of S&P 500 index, 1997-2010.

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