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Modern monetary policymakers consider a huge amount of information to evaluate events and contingencies. Yet most research on monetary policy relies on simple instrument rules and one relevant underpinning for this choice is the good empirical fit of the Taylor rule. This paper challenges the solidness of this foundation. We investigate the way the coefficients of the Taylor-type rules change over time according to the evolution of general economic conditions. We model the Federal Reserve reaction function during the Greenspan's tenure as a Logistic Smoothing Transition Regime model in which a series of economic meaningful transition variables drive the transition across monetary regimes. We argue that estimated linear rules are weighted averages of the actual rules working in the diverse monetary regimes, where the weights merely reflect the length and not necessarily the relevance of the regimes. Accordingly, an estimated linear Taylor-type reaction function tends to resemble the rule adopted in the longest regime. Thus, the actual presence of finer monetary policy regimes corrupts the general predictive and descriptive power of linear Taylor-type rules. These latter, by hiding the specific rules at work in the various finer regimes, lose utility directly with the uncertainty in the economy.

JEL classification E4, E5
Keywords: Instrument Rules, LSTR, Monetary Policy Regime, Risk Management, Taylor Rule.

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1 Introduction

Arguably, the main problem that monetary policy has to cope with is uncertainty. Alan Greenspan, former President of the Federal Reserve, maintained that uncertainty leads to a risk-management approach to policy in which "policymakers need to consider not only the most likely future path for the economy but also the distribution of possible outcomes about that path" (Greenspan 2004 p. 37).

In understanding the risk management approach, it is useful to characterize "general uncertainty" in terms of Knightian uncertainty and risk.[1] A crucial component of Greenspan's legacy is the predisposition to consider general uncertainty as an important determinant of monetary policy decision making. The management of general uncertainty, i.e. the management of the "continuum ranging from well-defined risk to the truly unknown" (Greenspan 2004, p. 37), represents the core of the so-called risk-management approach he adopted in his tenure. One consequence is that simple rules are likely doomed to miss changes in the monetary policy conduct driven by risk-management considerations. Those considerations consist of the judgment exercised in evaluating "the risks of different events and the probability that our actions will alter those risks" (Greenspan 2004, p. 38).

A monetary policy regime can be defined as the way policymakers address the issue of the instrument choice in order to reach one or more targets. Anecdotal evidence suggests that monetary policy is sensitive to special events and contingencies. Considering the recent monetary history of the US, examples of both were, amongst others, the crash in assets prices that occurred in 1987 and 2000, the acceleration in productivity in the mid-1990s, the Russian debt default in 1998 and the risk of deflation in 2002-3. If a set of one or more events and/or contingencies significantly modifies the way policy decisions are made, then a monetary policy regime switch occurs. Put another way, a policy regime switch is characterized by a change in the way monetary policy is conducted due to the occurrence of a set of events and/or contingencies. Accordingly, each monetary regime is characterized by a diverse rule of conduct that distinguishes it from the others.[2] Thus, considering contingencies and special events, the risk-management approach to monetary policy implies that "the decision makers need to reach a judgment about the probabilities, costs and benefits of the various possible outcomes under alternative choices for policy" (Greenspan 2004 p. 37).

1.1 The issue

Given that uncertainty-related concerns drive the changes in the policy stance, the importance of a monetary regime is not characterized by its time length, but, rather, by the impact of the event or the contingency on the behaviour of the policymakers. This definition of policy regime is more refined than the usual one, according to which established relations holding on a sufficiently long period of time are required to identify a regime. On the contrary, in this new definition, sudden events and contingencies that affect policy are sufficient to generate a regime switch.

Now, in an environment strongly characterized by uncertainty, to what extent, if any, can a linear monetary policy like the Taylor rule, provide guidance ex ante or only describe ex post the behavior of the central bank (CB hereafter)? To what extent finer regimes matter?

A "narrative answer" to this question is provided directly by the former Fed President:

[1] Knight's (1921) seminal dissertation splits general uncertainty into two distinct types of uncertainty: "risk" which is randomness with knowable probabilities, and therefore in principle eliminable, and "uncertainty" which is randomness with unknowable probabilities and therefore not eliminable.

[2] It is worth stressing that, while policymakers can observe real events, contingencies are more difficult to deal with because they may entail both risk (i.e. the probability distribution of outcomes is known) and uncertainty (i.e. probability distribution of outcomes is unknown).

"Indeed rules that relate the setting of the federal funds rate to the deviations of output and inflation from their respective targets, in some configurations, do seem capture the broad contours of what we did over the past decade and a half. And the prescriptions of formal rules can, in fact, serve as helpful adjuncts to policy [...]. But at crucial points, like those in our recent policy history - the stock market crash of 1987, the crises of 1997-98, and the events that followed September 2001 - simple rules will be inadequate as either descriptions and prescriptions of policy. Moreover, such rules suffer much of the same fixed-coefficient difficulties we have with our large-scale models" (Greenspan, 2004 p. 38-39).

A theoretical answer to this question is in the academic literature as well. Svensson (2003) argues that targeting rules allow a modelization of the monetary policy that is much closer to the monetary policy practice than instrument rules. In particular, they permit rational exploitation of all the information that the central bank has access to, but that is outside the scope of the model used to describe the economy. This information is distilled in what can be interpreted as the judgment of the central bank, which seems to be a crucial ingredient in the risk-management approach proposed by Greenspan.[3]

The aforementioned answers point to important limits of simple linear rules *à la* Taylor. Yet, we do not know to what extent, in practice, these limits matter. Furthermore, the larger part of the monetary policy literature uses this type of rules.

The purpose of this paper is to provide a quantitative answer to these questions focusing on special circumstances about which we have narrative and anecdotal evidence. If simple rules (as the Taylor rule) characterize well the overall Greenspan's tenure, then the management of special events and contingencies is of second order relevance. Instead, if the presence of finer regimes is a pervasive feature of the monetary policy, then a Taylor-type reaction function is somehow misleading. A targeting rule including judgment would probably be more effective to model the risk-management paradigm proposed by Greenspan.

It is worth noting that a policy rule maps the operating monetary regime into a relation that links the policy instrument with the bank's targets, or with their determinants. Building on this, we argue that if we empirically identify a change in the policy rule occurring in correspondence of an event and/or a contingency, we are also identifying a policy regime switch. While Greenspan has provided a narrative account of whether and when the Federal Reserve Bank has (and has not) undertaken such policy switches, the empirical literature has not yet produced evidences on his account of the evolution of the US monetary policy conduct. This paper aims to fill this gap in the literature.

We address this issue by investigating what happens to Taylor-type rules once linearity is not imposed to the specification. Specifically, we use a logistic smooth transition regression (LSTR) model, as developed by Terasvirta (1994) and improved by Van Dijk and Franses (2000). Various scholars, among others Kesriyeli et al. (2006) and Martin and Milas (2004), have already employed this type on non-linear econometric technique in monetary policy analysis. Such LSTR technique allows us to pick possible nonlinear behaviours without imposing their existence on the basis of some a priori knowledge. Indeed, by resorting to a LSTR model, we impose neither the existence of multiple regimes, nor the critical thresholds above/below which the different regimes take place. We do not impose the existence of multiple regimes because the model is free to produce a linear estimation if it is the case.[4]

[3] Using simulations based on the Svensson and Rudebush (1999) model of the US economy, Svensson (2005) shows that neglecting judgment as in the Taylor rule substantially worsens the monetary policy performance in terms of welfare.

[4] This is why we start from a linear estimation and extend it to a nonlinear environment, which almost preserves the structural features of the linear one. It is worth noting that the LSTR methodology differs from a Markov-Switching regimes estimation method, in that it requires that the regime changes are associated with the movements of a specific

We use this technique to detect deviations from the simple instrument rule and, when possible, to find the specific rule that characterizes a regime. Indeed, since the information that the central bank uses in judgment is often not available in the data[5], econometrics cannot always deliver the rule that captures the policymakers' behaviour in the finer regimes. Yet, in those cases, nonlinear econometrics allows us to find at least how many times and to what extent deviations from the simple average instrument rule occur.

The contribution of this paper is to show that, empirically, finer regimes exist and map into behaviors that differ from what is suggested by linear Taylor-type rules. The STR technique allows to detect endogenously regimes that by construction linear econometrics is doomed to miss. We provide evidence for a sequence of regimes that differ from the Taylor rule based on evidence drawn from analysis of the 18-year Greenspan era.[6] Since estimation over a sequence of regimes provides an average rule, the bottom line is that the presence of various finer regimes corrupts the predictive and descriptive power of the linear Taylor rule. Indeed, when finer regimes occurring in the face of special events and contingencies are considered together, the individual rules are shaken in a cocktail that averages out to the Taylor rule. For this reason, we believe that, when a sufficiently long period containing various regimes is considered, linear estimations tend to approximate to the Taylor rule. Yet these estimations lead to an average rule that, by hiding the specific rules occurring in the various regimes, loses utility directly with the differences among the regimes. Furthermore, since contingencies are an important ingredient of new regimes, and contingencies proliferate with uncertainty, it follows that a linear rule *à la* Taylor is doomed to lose utility along with growth in uncertainty in the economy.

The paper is structured as follows. In Section two, we briefly introduce the main features of Taylor-type rules and their major shortcomings. Then, in Section three we present the results of the linear estimations. The forth section is devoted to a brief description of the LSTAR specification that is the nonlinear estimation technique we use. In the following Section we report the results of the tests of nonlinearity. In the sixth Section we report the actual estimates of nonlinear Taylor rules and provide some comments on the results. Here, we focus on the ZLB contingency, the stock market crash in 2000 and the alleged stock market bubble in the late 90s. The seventh section is devoted to the discussion of the importance of choosing meaningful transition variables and the appropriateness of those employed in this work. We conclude with some general considerations about the implications of our findings on the meaning and utility of linear Taylor-type instrument rules.

2 The Taylor rule as an interpretative tool

The monetary policy rule proposed by Taylor (1993) is:

$$i_t = r^* + \pi_t + \beta_\pi (\pi_t - \pi^*) + \beta_y y_t$$

where i is the federal funds rate, r^* is the equilibrium real federal funds rate, π_t the average inflation rate over the contemporaneous and prior three quarters (GDP deflator), π^* the

variable with respect to a threshold. The LSTR model better fits our analysis since we believe that asset price misalignments and the declining distance between the nominal interest rate and the zero lower bound are the relevant variables leading the switches in the Fed's monetary policy stance, at least during some of the considered periods.

[5] King (2005) notes that the productivity acceleration in the US that started in 1995 was not visible until the vintages released in 1998. Yet, by talking and listening to people who work in business, already in May 1996 Greenspan accessed this information and exploited it to correct the forecast of the Fed's model.

[6] Several papers (for instance, Judd and Rudebusch (1998), Duffy and Engle-Warnick (2005), and Owyang and Ramey (2005)) have emphasized the existence of structural changes in the monetary policy corresponding to the appointments of the various Chairmen. We extend this line of research, focusing exclusively on the Greenspan era.

targeting inflation rate, and y_t the output gap.

Taylor suggests that expressing the federal funds rate in terms of the aforementioned linear function is not only a good description of Fed's monetary policy, but also a reasonable policy recommendation for central bankers committed to maintaining a low inflation environment. Not everybody has agreed with such claim, yet the extent of the disagreement varies between authors.[7] While some have criticized the limited prescriptive use of the Taylor rules[8], other researchers have stressed the existence of possible empirical shortcomings.[9] Notwithstanding all these critiques, after its first formulation, the Taylor rule has probably become one of the most investigated and estimated relationship in economics. All in all, the Taylor rule is considered an important benchmark both for the design of policy rules and for the *ex-post* empirical investigations of past monetary policy decisions. This is in line with the two hypotheses at the basis of this work: Taylor-type rules manage to detect the broad contours of monetary policy decisions but, to say it with Svensson, do not capture their judgment component. Building on this observation, our investigation focuses on the critical fact that their linear form prevents them from detecting potential significant switches in the monetary policy stance over time.

A common modification of the classical Taylor rule is the addition of at least one lagged interest rate term. The reasons for doing so belong to both the theoretical and the empirical realms. From the empirical point of view, the estimation of a classical Taylor rule generates highly serially correlated residuals which can be dealt with by adding some lags of the dependent variable among the regressors. From the theoretical point of view, there are several reasons for expecting monetary authorities to change the interest rates only gradually. In brief, it seems that a common denominator of these reasons is a trade-off between the CB speed in affecting the economy and the effectiveness of the monetary policy.[10] In line with such arguments, we can think that the CB sets the interest rate as a weighted average of the target rate and the last period(s) rate(s). This can be written as:

$$i_t = (1-\rho)\widetilde{i}_t + \rho i_{t-1} \tag{1}$$

where, assuming a contemporaneous rule, the target rate is $\widetilde{i}_t = \alpha + \beta_\pi(\pi_t - \pi^*) + \beta_y y_t$.

In the empirical literature, the coefficient ρ is found to be fairly large (close to 1) and highly significant for any time period and country. This supports the idea that CBs adjust the interest rate with a certain inertia, or, alternatively, that the interest rates move rather smoothly. However, Rudebusch (2002) observes that, while interest rate smoothing would

[7] For instance, Kozicki (1999) argues that Taylor-type rules do not produce useful recommendations because they are not robust to changes in the details of their specification and to alternative measures of their determinants.

[8] Svensson (2003a p. 428) argues that "..the rule is incomplete: some deviations are allowed but there are no rules for when deviations from the instrument rules are appropriate". Woodford (2001 p. 236) argues, for instance, that "the Taylor rule incorporates several features of an optimal monetary policy, from the standpoint of at least one simple class of optimizing models. The response that it prescribes to fluctuations in inflation or the output gap tends to stabilize those variables, and stabilization of both variables is an appropriate goal, at least when the output gap is properly defined. Furthermore, the prescribed response to these variables counteracts dynamics that could otherwise generate instability due to self-fulfilling expectations". He also argues, however, that "at the same time, the original formulation may be improved upon."

[9] Several authors have raised concerns also regarding the possibility of drawing conclusions about past policy decisions on the basis of estimated Taylor-type rules. For instance, Orphanides (1998) notes that the use of ex-post revised data in estimating Taylor Rules may lead to very different conclusions from those obtainable resorting to real-time data.

The time series properties of the variables (which may possibly lead to spurious regressions), the *ad hoc* specification of the functional form, the instability of the parameters and the sample selection biases are problematic issues still largely debated in the literature. See, for instance, Siklos and Wohar (2005).

[10] In the appendix we offer an overview of most of the rationales identified to explain the CBs" interest smoothing motives. For a thorough discussion on this issue see Lowe and Ellis (1997), Rudebusch (1995, 2001, 2002), Gerlach-Kristen (2004), Woodford (2001, 2003a, b), Amato and Laubach (1999), Orphanides (1998), Sack and Wieland (2000), Aoki (2003), Goodfriend (1987, 1991), Cuckierman (1996), Roley and Sellon (1995), Levin, Wielandand Williams (1999), Bullard and Schaling (2002), Caplin and Leahy (1996), Goodhart (1999), Kuttner (2001), Svensson (2003a).

imply that the interest rates are quite predictable, actual data do not exhibit such a feature. Accordingly, he suggests that, in fact, there is no interest rate smoothing at a quarterly frequency, but rather highly permanent shocks to which CBs respond. It is the persistent nature of the shocks that motivates the persistence of the interest rates[11]. He concludes that lagged interest rates into the Taylor rule possibly reflect an omitted variables problem rather than a truly smoothing (or partial adjustment) behaviour of the CB. Such conclusions are challenged by English et al. (2002) and Castelnuovo (2003), who test the existence of interest rate smoothing at quarterly frequencies in forward looking Taylor rules. Castelnuovo concludes that both serial correlation (due to persistent omitted variables) and authentic interest rate smoothing are supported by the data.[12] Gerlach-Kristen (2004) follows a different approach and arrives to very similar conclusions. Therefore, from a purely econometric viewpoint, lagged interest rates in the Taylor rule remain a plausible means to capture the interest rate inertia present in the data, but they might also hide an omitted variable problem.

In order to take this much debated and (still) unsettled issue into account, in what follows we estimate several different specifications of linear Taylor rules, which all encompass a smoothing (i.e. autoregressive) part and some of them include additional explanatory variables, so-called Taylor-type rules.

The dynamic specification of the Taylor rule is extremely important in our work. A correct specification of the linear model is necessary if we want to econometrically test for the presence of nonlinearity. Heteroskedasticity and residual serial autocorrelation tend to lead to the over-rejection of the correct hypothesis of model linearity and, therefore, it is crucial to encompassing a smoothing component. From both LM tests for serial correlation and the inspection of the ACF and the PACF, it turns out that in our sample, two autoregressive terms are necessary to get rid of any serial autocorrelation in the errors of the considered Taylor-type rules. Accordingly, we set a specification of the Taylor-type equations that encompasses two lagged interest rates [13].

3 The data and the linear estimation

We use US quarterly data from 1988:Q3 to 2004:Q1.[14] All the series have been downloaded from the web-site of the Federal Reserve Bank of St. Louis with the exception of the S&P500 series and the stock returns, computed on the basis of the S&P500 series, which have been downloaded from Datastream.

As a measure of inflation, following Taylor (1993), Judd and Rudebush (1998) and many other authors, we use the average over the contemporaneous and the three lags of the four-quarter inflation rate ($\overline{\pi}_t = \sum_{i=0}^{3} \pi_{t-i}/4$). The quarterly inflation rate π_s, in its turn, is constructed as follows: $\pi_s \equiv (p_s - p_{s-1})$, where $p_s = 100 \cdot \ln P_s$ and P_s is the GDP chain-type price index. The output gap y_t is defined as the difference between the log of the real GDP level and the log of the real potential GDP, as estimated by the Congressional Budget Office.[15]

[11] He supports such a claim on the basis of the term structure of the interest rates and of a direct test (on a nested model in levels) on the interest rate smoothing against serial correlation hypothesis.

[12] Welz and Osterholm (2005) argue that the test employed by Castelnuovo and English et al. is not robust and tends to overreject the hypothesis of serial autocorrelation. This finding certainly casts some doubts on the strength of the conclusions reached on the basis of their tests, yet not on the existence of the interest rate smoothing itself.

[13] The presence of two lagged interest rates is not new in the literature, see for instance Judd and Rudebusch (1998), and Woodford (2003a p. 41), which proposes to rewrite the specification above as $i_t = (1-\theta_1)(\widetilde{i_t}) + \theta_1 i_{t-1} + \theta_2(i_{t-1} - i_{t-2})$, where $\theta_1 = \rho_1 + \rho_2$ and $\theta_2 = -\rho_2$. The interest rate is set in response to changes in the level of $\widetilde{i_t}$ according to the partial adjustment mechanism above.

[14] This is the sample of observations we get after adjustments. The actual starting point of the original sample is 1987:Q4 since we focus only on the "Greenspan's leadership" in order to avoid to capture regime switching related to compositional changes of the Federal Open Market Committee.

[15] We borrow the definitions from Castelnuovo (2003).

Since we are focusing on the US, as measure of the interest rates we use the Federal Funds rates.

We estimate the non-augmented linear model in the following form:

$$i_t = a + b_\pi \overline{\pi}_t + b_y y_t + \rho_1 i_{t-1} + \rho_2 i_{t-2} + \xi_t \tag{2}$$

where the coefficients b_π and b_y are implicitly defined.

The OLS estimates[16] of the coefficients of this linear non-augmented specification are reported in the second and third columns of Table 1. The degree of interest rate smoothing, equal to the sum of the ρ_s, is 0.8421 and satisfies the necessary condition for the stationarity of the Funds rate series. The estimated coefficients reported in Table 1 are not far from the values one would expect from the estimation of a Taylor rule. In the non-augmented specification, the long run (LR) coefficient for inflation is very close to Taylor's prediction (i.e. 1.5), whereas the LR coefficient of the output gap is above the "suggested" 0.5[17].[18] The residuals from the regression of equation (2) are plotted in Figure 1.

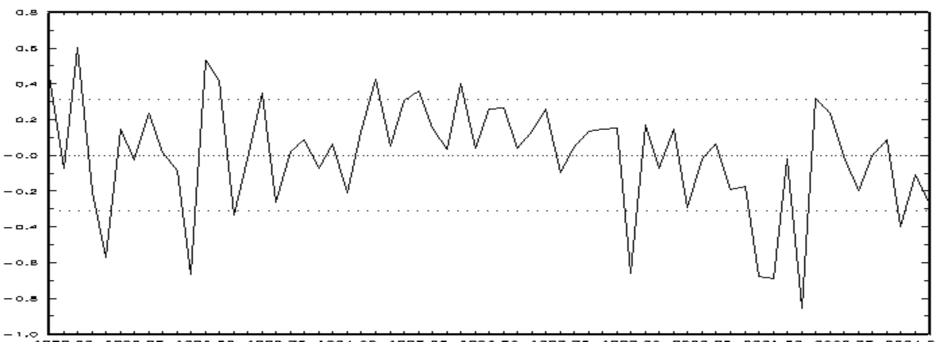

Figure 1. OLS Residuals from a linear non-augmented Taylor rule

At first sight, the rule seems to capture well the behaviour of the authorities, however it is noteworthy that the residuals are consecutively and significantly different from zero in more than one quarter, namely in 1991, 1994-1996 and in the period 1999-2002. Negative residuals correspond to periods in which the estimated rule is conducive to fitted federal fund rates higher than the actual ones.[19] According to this finding, in those periods the US monetary policy seems to have been relaxed beyond what was suggested by the inflation and the output gap deviations.

The behaviour of the residuals suggests that the non-augmented linear specification does not perfectly catch the actual behaviour of US monetary authorities. The mere inspection of the graph does not allow one to say whether this limited ability to replicate the data is related to omitted significant variables and/or to the imposition of a linear and time invariant specification of the model. We investigate these possibilities firstly by augmenting the basic

[16] At this stage we could estimate the linear Taylor rule by means of alternative econometric techniques, as for instance OLS and GMM. We directly start with an OLS estimation because GMM is not efficient in samples as small as this one, and the selection of the instruments is (somehow obscurely) driving the results.

[17] A joint Wald test on $\beta_\pi = 1.5$ and $\beta_y = 0.5$ leads to reject the null hypothesis. However, performing two disjoint tests for the two hypotheses originates a controversial result. The null hypothesis of an output coefficient equal 0.5 is rejected, while the hypothesis for the inflation coefficient cannot be rejected.

[18] As Yellen (2004, p. 46) notes, since movements in unemployment commonly lead inflation, the high coefficient of the unemployment gap in the Taylor rule means that the Greenspan Fed typically behaved preemptively. This explanation also applies to the high coefficient of the output gap in the estimation of the Taylor rule we report.

[19] For positive residuals, the opposite reasoning holds.

rule with additional (possibly omitted) variables, then by considering a nonlinear form of the augmented and non-augmented specifications.

In this section we exclusively focus on the linear specifications. The linear augmented Taylor-type rule we estimate is:

$$i_t = a + b_\pi \overline{\pi}_t + b_y y_t + \omega_z' z_t + \rho_1 i_{t-1} + \rho_2 i_{t-2} + \xi_t \tag{3}$$

where z_t is a vector of additional variables that can be significantly added so as to augment the classical Taylor functional form. Following economic intuition and the results of Castelnuovo (2003) and Gerlach-Kristen (2004), we consider among the possible additional variables the spread between the Moody's BAA corporate bond index yield and 10-year US Treasury note yields (i.e. z_2). We also include the difference between the 10-year US Treasury note and the 1-year US Treasury note yields (i.e. z_1).[20] These variables are statistically significant and improve the overall fit of the model as it can be seen from the values of the Akaike criteria reported in the last row of Table 1.

	Non augmented		Augmented			Non augmented	Augmented
Coefficient	Estimate	St. Error	Estimate	St. Error	*LR-coefficient*	Value	Value
a	0.3131	0.1254**	2.2465	0.3050***	c	1.9700	6.0212
b_π	0.2330	0.0857***	0.4740	0.0804***	$\beta\pi$	1.4660	1.2704
b_y	0.1555	0.0404***	0.1092	0.0343***	βy	0.9780	0.2927
ω_{z1}			-0.3476	0.0879***	$\beta z1$		-0.9317
ω_{z2}			-0.4786	0.0694***	$\beta z2$		-1.2828
ρ_1	1.4284	0.1018***	0.9490	0.1105***			
ρ_2	-0.5873	0.0893***	-0.3221	0.0783***			
	Summary statistics						
Sum of squared residuals	5.9694		3.3074				
Akaike IC	-2.1977		-2.7247				

Table 1.OLS estimations. (Where z_1 is the U.S. Treasury note spread and z_2 the BAA spread)

It is worth noting that augmenting the Taylor rule by means of two additional regressors reduces the degree of interest rate smoothing from 0.8411 to 0.6269. This finding supports the hypothesis that at least a part of the serial autocorrelation of the errors from the non-augmented specification is due to omitted variables, and not to actual interest rate inertia. As to the signs of the additional variables they follow economic reasoning. Finally, note that the LR coefficient of inflation remains greater than 1, as it is in the non-augmented specification, whereas the LR output gap coefficient falls from 0.98 to 0.29. All in all, the augmented specification seems preferable to the non-augmented one.

Figure 2 plots the residuals of the linear augmented specification (3). Apparently, the addition of two explanatory variables has contributed to reducing the correlation in the errors and the positive spikes in the period 1994-1996, yet it has not solved the series of statistically significant negative residuals that are still present. In addition, augmenting the Taylor rule

[20] The BAA spread is a measure of credit risk. It is determined by the investors' risk aversion and the solvency risk of the companies issuing the assets encompassed in the index. When the spread widens, an aggregate negative shock is likely to have hit (or it is expected to hit) the economy and/or the financial markets. The central bank usually reacts to such kind of events by relaxing monetary policy. Therefore, we expect the variable to enter with a negative sign in the Taylor-type rule. The spread between long and short yields, instead, is likely to reflect temporary changes in expected inflation. If the investors expect the inflation rate to fall temporarily, they will also expect federal fund rates to go down. Accordingly, they will invest so as to also reduce the 1 year yield. The 10 years yields will be almost unaffected since the inflation and the interest rates are expected to go back to normality in the medium and long run. An increase in the spread between the two yields is likely to reveal expectations of low inflation in the short term. If the central bank also expects the inflation rate to temporarily fall, it often reduces the overnight interest rates. In accordance with this reasoning, we expect the variable to enter with a negative sign in the Taylor-type rule.

has led to significantly positive residuals in the period 2002-2003. Although the overall fit of the rule is improved by the addition of two informative variables, this is not the case in all periods and over certain time intervals the fitted interest rates significantly differ from the actual values. This suggests that linear Taylor-type rules, however defined, are unable to produce exact results at each point in time, and may instead yield significant errors: a more flexible tool is required so as to let the rules change when certain circumstances occur.

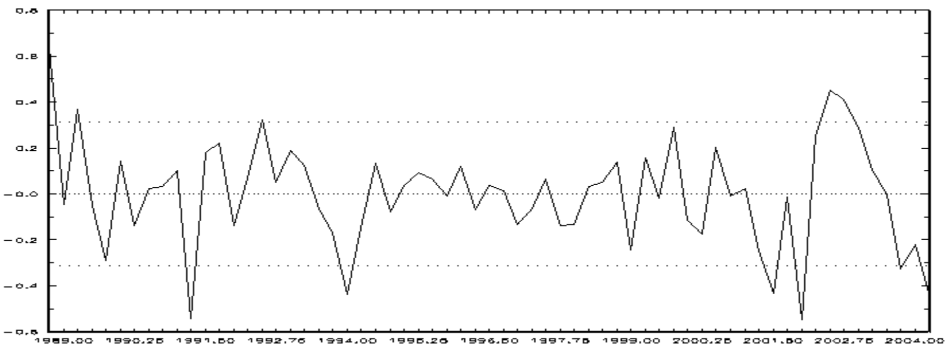

Figure 2. OLS Residuals from the augmented Taylor rule.

4 The nonlinear model

Following closely the work of Van Dijk and Franses (2000) and Van Dijk et al. (2000) we assume that the model to estimate looks like:

$$y_t = \phi x_t + \varepsilon_t, \tag{4}$$

where x_t is a vector of regressors which includes a constant, some explanatory variables and, possibly, some lagged values of y_t. The model in the equation above is characterized by the linearity/constancy of the coefficients ϕ. A smooth transition (STR) model starts from the assumption that there are (at least) two regimes with two different sets of coefficients: Φ_1 and Φ_2 and a transition variable which determines the movements across the regimes[21].

In very general terms, a two-regime smooth transition model for a univariate series y_t observed at time t=1-p,1-(p-1),..-1,0,1,...T-1,T, is given by:

$$y_t = \phi_1' x_t (1 - G(l_t; \gamma, c)) + \phi_2' x_t G(l_t; \gamma, c) + \varepsilon_t. \tag{5}$$

The two sets of coefficients, Φ_1 and Φ_2, characterize the two extreme regimes with the transition function, $G(l_t; \gamma, c)$, assuming that its edge values are 0 and 1. The variable l_t is the transition variable, the constant value c is the threshold and corresponds to the value of the transition variable which separates one regime from the other. Instead, the constant γ, is the speed parameter, that determines how fast the transition between the regimes occurs. Both c and γ are estimated by the model.

It is worth noting that different functional forms of $G(l_t; \gamma, c)$ correspond to different regime switching behaviours. The most common ones are the exponential specification[22], which is

[21] Note that it is this feature that distinguishes STR models from Markow Switching regimes models, where the transition across regimes does not depend on a specific variable. Some very recent papers have employed Markov Switching regime models to detect the existence of multiple regimes in U.S. monetary policy. See for instance Owyang and Ramey (2005), and Duffy and Engle-Warnick (2004).

[22] The exponential specification looks like $G(l_t; \gamma, c) = 1 - \exp\left\{-\gamma (l_t - c)^2\right\})$

used when there is an interest in symmetric regimes associated with small and large absolute values of the transition variable, and the logistic one. Since we exclude a symmetric behaviour, in this work we only focus on the logistic transition function. This can be written as:

$$G(l_t; \gamma, c) = (1 + \exp\{-\gamma(l_t - c)\})^{-1}, \qquad \gamma > 0$$

Interestingly, there are two alternative (compatible) interpretations of a STR model[23]. The model can be seen as a regime switching representation that allows for two regimes, associated with the extreme values (0,1) of the transition function $G(l_t; \gamma, c)$, where the transition from the first to the second regime is smooth or, alternatively, as a *"continuum" of regimes*, each associated with a different value of $G(l_t; \gamma, c)$, between the extremes 0 and 1.

In practice, after having specified a linear model with the correct number of autoregressive terms[24], the null hypothesis of linearity is to be tested against the alternative of (STR) nonlinearity. This test has to be repeated for all the possible transition variables, and those for which the linear model is rejected have to be chosen as possible candidates. Once the functional form of $G(\cdot)$ is defined, the parameters of the STR model have to be estimated by means of a quasi-maximum likelihood technique. To conclude, the estimated model undergoes a series of diagnostic tests. On the basis of the tests' results, the model can be changed where necessary and the cycle repeated.

In the next sections we will proceed along the guidelines above. We have already started estimating the linear model; therefore, we will pass now onto testing the assumption of linearity. Following this, we will estimate the appropriate specification of the LSTAR model.[25]

5 Testing for the linearity of the model

Now, we move on to test the null hypothesis of the linearity of the model against a nonlinear specification. We are interested in testing whether (i) extreme movements in the stock markets or (ii) changes in the perceived risk to hitting the ZLB and end up in a liquidity trap have temporarily affected the decisions of the Federal Reserve Bank. Given this goal, we find it is convenient to resort to the STR estimation method and to impose to the estimation that the nonlinearity (if any) has to be associated with, either (i) a stock market related variable or (ii) a variable capturing the perceived risk of hitting the ZLB. Consistently, we run a series of tests of linearity for a group of asset-prices related variables and the one-period lagged interest rate (i_{t-1}), and we select the variables which are more likely to drive regime switches.

As regards asset prices, we adopt diverse, stationary, measures of stock market returns. We consider stock markets returns calculated over different time horizons including both short and long lasting stock market performance.[26]

We look at a quarterly measure of monthly returns ($ret1m$) calculated on the S&P500 index, the quarterly returns ($ret3m$), the 6-month returns ($ret6m$) and the moving average

[23] Other models tackle the possible existence of multiple regimes in alternative fashions. Researchers, for instance, are quite familiar with threshold autoregressive (TAR) models. A STAR model differs from a TAR model in the way the switches between regimes occur. In a STAR model the transition is smooth, with a speed that is estimated on a case-by-case basis. In a TAR model, instead, an abrupt change across regimes is imposed. It follows that STAR models involve less restrictions than TAR models, as they relax the requirements on the speed of transition (which is infinite in the TAR case), and consequently, nest the TAR specifications

[24] Since the rejection of linearity could stem from the misspecification of the linear model (see Van Dijk et al. 2000), the linear functional form has to be carefully characterised.

[25] To produce the nonlinear estimations we have modified the GAUSS codes on "Regime-Switching Models for Returns" written by Van Dick and available on his web site.

[26] We focus on stock market indicators in level rather than in variation. Rigobon and Sack (2003) use a different approach focussing on measure of market turbulence. D'Agostino et al. (2005) set the analysis in terms of stock market volatility.

over 6 months of the monthly returns, transformed in quarterly frequency ($retma$) and, lastly, the quarterly change in the level of S&P500 index (dsp). In the tests that we will present below, we also consider the first and the second lags of all the previous variables.[27] Finally, to test for generic parameter constancy, a time trend t is encompassed among the candidate transition variables. It should be noted that the choice of the best transition variable among the alternatives is performed in a subsequent step on the basis of the results of the tests for nonlinearity. Table 2 reports the value of the so-called LM3 test, a LM-test type with F-distribution, testing the null hypothesis of linearity.[28]

		ret1m(t)	*ret1m(t-1)*	*ret1m(t-2)*	*ret3m(t)*	*ret3m(t-1)*	*ret3m(t-2)*	*ret6m(t)*	*ret6m(t-1)*	*ret6m(t-2)*
Non augmented	*F-test*	1.6349	3.4286	2.0613	2.4368	3.6146	1.5382	3.67	2.23	0.65
	p-values	0.1041	0.0008	0.0326	0.0114	0.0000	0.1342	0.0004	0.0205	0.9603
Augmented	*F-test*	1.3698	2.289	1.7941	2.1185	1.7928	0.8362	2.0835	0.9061	0.87
	p-values	0.2003	0.0147	0.0614	0.024	0.0617	0.662	0.0266	0.5857	0.6249

		retma(t)	*retma(t-1)*	*retma(t-2)*	*dsp(t)*	*dsp(t-1)*	*disp(t-2)*	*i(t-1)*	*time*
Non augmented	*F-test*	3.5464	3.1586	0.5677	2.1108	5.3841	2.417	2.20008	3.8038
	p-values	0.0006	0.0016	0.8831	0.9189	0.0000	0.0121	0.0277	0.0003
Augmented	*F-test*	2.0742	1.5837	0.8854	2.1615	2.3325	2.3297	3.4124	6.3982
	p-values	0.0273	0.1117	0.6082	0.0212	0.0129	0.013	0.0007	0.0000

Table 2. F-statistics and p-values of LM3 score tests for STR nonlinearity. Full sample

On consideration of the results, we conclude that there is strong evidence in favour of a nonlinear specification of the Taylor-type rules. Both asset prices[29] and past interest rates are likely to be responsible for an alleged nonlinear behaviour of the Fed.

According to the p-values of the tests, the asset prices variable for which linearity is more strongly rejected is dsp_{t-1}. This does not necessarily entail that the best estimates of the model have to come from an estimation where dsp_{t-1} is the transition variable. Any variable that passes the test for nonlinearity is a potential candidate, and its validity has to be evaluated on the basis of the overall performance of the estimated model.[30] For instance, time trend turns out to be one of the most significant transition variables. However, the model estimated with the time trend as transition variable is neither convincing nor consistent with market commentary and economic reasoning. Time is, in fact, a special variable; it has to be interpreted as a source of non-constancy of the parameters rather than a variable driving regime switches.

5.1 The specification of the LSTAR model

Whilst a linear Taylor-type rule does quite a good job in describing the overall evolution of the interest rate over time, it does not allow detection of those policy decisions that have been guided by considerations not directly related to the changes in the output gap and inflation. For instance, CBs' concerns about alleged asset prices misalignments or the ZLB trap play no role in a linear rule. A possible way to address this issue is to allow the coefficients of the rule

[27] We do not explore further lags because they would imply an unrealistic delayed response of the central bank to asset prices misalignments. We do not have any metrics for the fundamental value of asset prices and this prevents us from investigating the alleged positive and negative bubble components of asset prices.

[28] For an extensive description of the test see also Lukkonen et al. (1988), and Davies (1978,1987) for the related *nuisance parameters* problem.

[29] It is worth noting that only the measures of asset prices that do not go too far into the past (at most, first lags) affect the linearity of the response. Such findings corroborate the intuition that asset prices influence monetary policy only in special circumstances and for limited periods of time.

[30] We thank Anne Peguin Feisolle for useful clarifications on this point.

to change in the face of events and contingencies.[31] Splitting the sample in different periods and estimating different parameters is a possible solution but it has major shortcomings. In particular, the different periods must be identified on the basis of a priori knowledge, the specification requires 0/1 (on/off) regime switches, and the coefficients of the variables relevant only in extreme events have not to be significantly different from zero in "normal times". On the contrary, the nonlinear technique does not require a priori knowledge of time periods, it does not postulate a 0/1 regime switching behaviour, and it does not impose that variables such as asset prices are determinants of monetary policy decisions at all times.

If we allow all the parameters in the model to vary across regimes, the linear specification can be transformed into:

$$i_t = a_t + b_{\pi,t}\overline{\pi}_t + b_{y,t}y_t + \rho_{1t}i_{t-1} + \rho_{2t}i_{t-2} + \eta_t \tag{6}$$

where

$$\begin{aligned}
a_t &= a^L * (1 - G(l_t;\gamma,c) + a^U * G(l_t;\gamma,c), \\
b_{\pi,t} &= b_\pi^L * (1 - G(l_t;\gamma,c)) + b_\pi^U * G(l_t;\gamma,c), \\
b_{y,t} &= b_y^L * (1 - G(l_t;\gamma,c)) + b_y^U * G(l_t;\gamma,c), \\
\rho_{1t} &= \rho_1^L * (1 - G(l_t;\gamma,c)) + \rho_1^U * G(l_t;\gamma,c) \\
\rho_{2t} &= \rho_2^L * (1 - G(l_t;\gamma,c) + \rho_2^U * G(l_t;\gamma,c)
\end{aligned}$$

All the parameters are regime dependent, and, according to the representation introduced with equation (5), they can be split in lower (ϕ^L) and upper (ϕ^U) regime parameters. We wish to emphasize that we do not impose any restriction on the speed of transition γ and the threshold c. We allow the data i) to reject the possibility that two extreme regimes exist, ii) to find when (if ever) they occur, and iii) to determine what they look like. In other words, before estimating the nonlinear Taylor-type rule, we cannot say whether the lower and the upper regimes are coincident or far apart, whether the threshold (when more than one regimes is present) is positive, negative or equal to zero, and, in the case of asset prices, whether bubbles or market crashes are relatively more important determinants of the nonlinearity of the monetary policy behaviour.

When we estimate augmented Taylor-type rules, we proceed in a similar fashion and the coefficients of the additional terms (z_t) follow the same "splitting" treatment of the variables above. The model in equation (6) can be rewritten as:

$$\begin{aligned}
i_t &= (1 - G(\cdot))(a^L + b_\pi^L\overline{\pi}_t + b_y^L y_t + \omega^{L\prime}z_t) + (G(\cdot))(a^U + b_\pi^U\overline{\pi}_t + b_y^U y_t + \omega^{U\prime}z_t) + \\
&\quad + \rho_1^L(1 - G(\cdot))i_{t-1} + \rho_2^L(1 - G(\cdot))i_{t-2} + \rho_1^U G(\cdot)i_{t-1} + \rho_2^U G(\cdot)i_{t-2}
\end{aligned} \tag{7}$$

6 Nonlinear estimation: unveiling finer regimes

In this section we report the actual estimates of nonlinear Taylor rules, as specified in equation (7), and some comments on the results.

[31] It is worth stressing that merely augmenting a linear classical rule, as it has been done in the literature, so as to encompass some measure of asset prices in the specification, does not give a rule that is suitably flexible to pick up rare events, such as crashes in the equity market.

6.1 The zero lower bound case

In the United States the risk of deflation materialized after the burst of the asset bubble in 2000[32]. Indeed, the aggressive monetary easing mitigated the fallout of the bubble, but it also drew the interest rate closer to the ZLB. The Fed considered deflation a low probability contingency for the U.S. economy. Nonetheless, according to Greenspan, it determined an important change in policy in 2003. It is instructive that Greenspan used this very episode to explain the risk-management approach that he has been following during his tenure.

> "In the summer of 2003, for example, the Federal Open Market Committee viewed as very small the probability that the then-gradual decline in inflation would accelerate into a more consequential deflation. But because the implications for the economy were so dire should that scenario play out, we chose to counter it with unusually low interest rates" (Greenspan, 2005).

The relevance, in practice, of the risk-management approach and the crucial role of judgment are even more apparent if we broaden the policy horizon so that more contingencies can be considered at once. A case in point is provided by the possibility that an asset bubble bust, requiring an aggressive cut of the interest rate, ends up entrenching the economy in a liquidity trap.[33]

These considerations motivated us to investigate if, and to what extent, data could identify a source of nonlinearity in the U.S. monetary policy generated by concerns on the ZLB and deflation. The nonlinear estimates for the augmented nonlinear rule are reported in Table 3.[34]

	ZLB regime		*No ZLB regime*	
Coefficient	Estimate	St.error	Estimate	St.error
a			2.9120	0.3017***
b_π			0.6192	0.0799***
b_y			0.1532	0.0308***
ω_{z1}			-0.3883	0.0812***
ω_{z2}			-0.6934	0.0707***
ρ_1	0.9179	0.0383***	0.7889	0.1028***
ρ_2			-0.2561	0.0070***
Model parameters				
Speed of transition (γ)	20.7970		0.8101***	
Threshold c	3.0149		0.0773***	
Summary statistics				
Sum of squared residuals	2.0620			
Akaike Info Criterion	-3.1010			

Table 3. LSTAR estimates. ZLB case ($z_1$is the U.S. Treasury note spread and z_2 the BAA spread)

[32] See Bernanke (2002) on this point.

[33] Robinson and Stone (2005) aim at providing an answer to the question of how policymakers should behave in the face of those contingencies. They conclude that even neglecting the informational difficulties facing policymakers in practice, the optimal policy depends neither linearly nor continuously on the parameters of the economy and time.

[34] We focus only on the results based on the augmented rule because it overperforms the non-augmented one in all of the specifications. However, the estimations build on the non-augmented rule are available upon request.

Figure 5 plots the transition variable and the threshold.[35] First of all, we can observe that the threshold for the interest rate is roughly equal to 3%[36], which implies that when the interest rate falls below that threshold, monetary policy enters a new regime where the policy instrument does not respond as usual to its determinants. Second, while the estimates of the NO-ZLB regime do not differ much from the linear ones, we do not identify a proper alternative Taylor-type rule for the ZLB-regime. The best specification we manage to find is a purely (and highly) autoregressive process.

It is worth stressing that even though the threshold divides the graph into two clear areas, the transition function is a logistic one, and this entails a smooth transition from one extreme regime to another. In this case, the speed of transition is sufficiently high to imply a relatively sharp movement from the upper to the lower regime. The transition function is plotted against the ordered values of the transition variable i_{t-1} in figure 3.

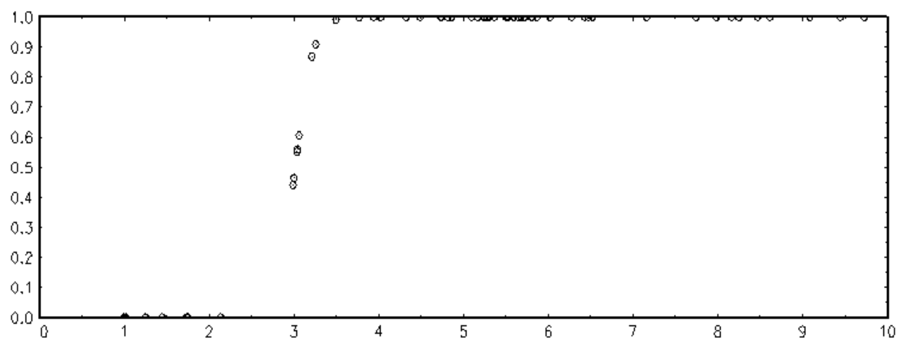

Figure 3. Transition function against i_{t-1}- ZLB case.

We are aware that the rule we find for the ZLB regime is far from satisfactory. Even so, the aim of this work is to see whether finer monetary policy regimes exist, in relation to which macroeconomic phenomena (i.e. transition variables) and, lastly, whether allowing monetary policy to deviate from Taylor-type rules improves the fit of the model. To tackle the last two points, we resort both to graphical analysis and to some synthetic econometric indicators. Starting from the latter, we notice that the Akaike Information Criterion passes from -2.725 of the augmented linear form to -3.101 of the augmented nonlinear one. This suggests there is an overall improvement in the fit of the model. By plotting both the linear and the nonlinear estimation residuals, we have another tool to compare the fit of the model in each period of time. The inspection of the upper graph in Figure 4 reveals that there is not a big difference between the two series of residuals up to 2002. From 2002 onwards, however, things change. The residuals of the linear estimation (dashed line) first overshoot and then undershoot zero, while the residuals of the nonlinear rule (solid line) fluctuate more closely around zero (dotted line). The lower graph in Figure 4 represents the difference between the squared linear and nonlinear residuals. Anytime the line is above zero the residuals of the nonlinear model are closer to zero than those of the linear specification; and therefore the nonlinear model performs better than the linear one. As one can see, this line is constantly above zero after 2001. Interestingly, this span of time coincides with the periods where monetary policymakers had to face the risk of falling into a ZLB trap. Thus the model succeeds in detecting that ZLB concerns have affected the monetary policy, roughly, from 2002 to 2003.

[35] This makes it easier to associate the various regimes to the time periods they relate to.

[36] Figure 5 plots the transition variable and the threshold. This makes easier to associate the various regimes to the time periods they relate to.

To sum up, allowing the interest rate to be the transition variable driving the switches of monetary policy across different regimes, the model manages to identify two regimes. One regime (i.e. the NO-ZLB one) is characterised by a monetary policy which is summarized by a Taylor-type augmented rule. The other regime (i.e. the ZLB one), instead, is characterized by low and flat interest rates and, not by chance, corresponds roughly to the period when, according to anecdotal evidence, the economy was considered in danger of falling into a liquidity trap.

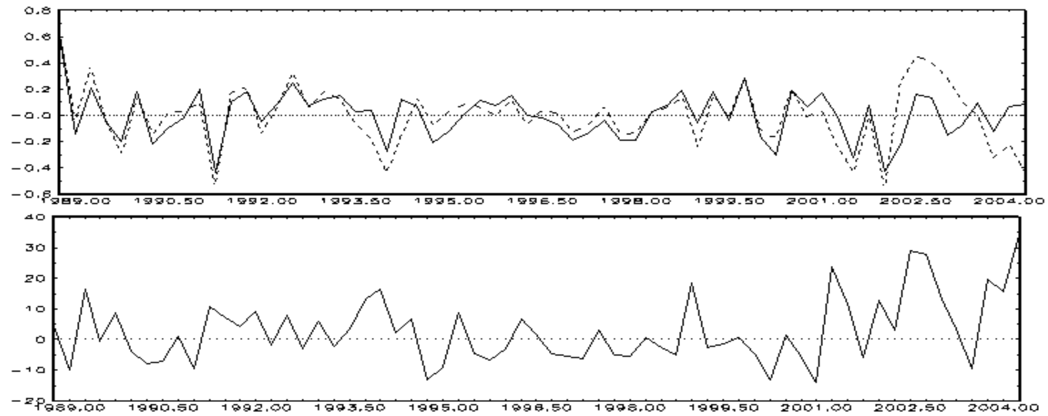

Figure 4. (UP) Residuals from linear (dashed) and nonlinear (solid) Taylor-type rule. ZLB case. (LOW) Difference squared linear and nonlinear residuals

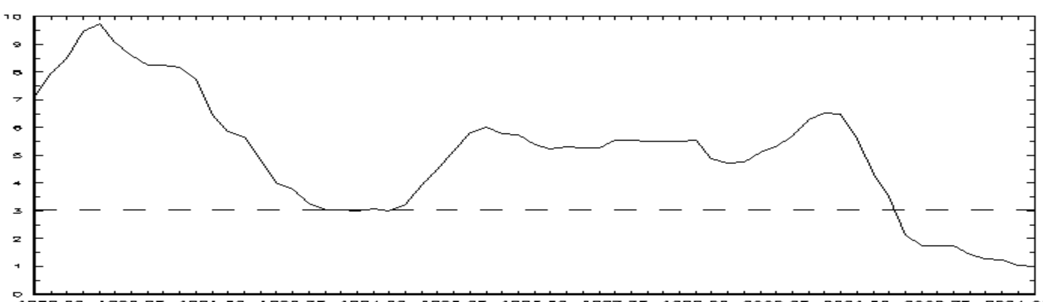

Figure 5. Transition variable (i_{t-1}) over time and threshold - ZLB case.

6.2 Asset prices misalignments cases

To study the effects of asset prices and asset prices misalignments on monetary policy, asset prices have been encompassed in the specification of estimated Taylor rules in different ways, according to the role allegedly played in the central bank's decision making process.[37] The approach we propose in this paper treats asset prices as a transition variable in a regime switching model. Accordingly, asset prices are thought to be responsible for regime switches in the CB's behaviour.

[37] In previous studies asset price measures have been included either as an additional regressor in a linear rule or among the external instruments in a GMM or 2SLS estimation.

6.2.1 The stock market crash (2000-2001)

In the last 5 years, a large debate has grown about the actual relationship between price stability and financial instability. This discussion is strictly linked to the broader debate about the role of asset prices in monetary policy. While the debate has long revolved around whether price stability does or does not entail financial stability, the question that can be posed is slightly different and twofold, namely, i) whether financial instability may jeopardize price stability, and ii) to what extent CBs have to keep this fact into account.[38]

In this respect we investigate if financial instability concerns have actually affected the conduct of US monetary policy in a nonlinear way.[39] Anecdotal and narrative evidence suggests that negative price misalignments (i.e. crashes) have a relatively larger importance than alleged positive misalignments. Until very recently, central bankers strongly objected to the idea that the CBs had to react to positive asset prices misalignments (i.e. bubbles), whereas central banks have openly reacted to stock crashes by flooding the markets with liquidity. This happened for the Federal Reserve Bank at least twice in the last 20 years (namely, in 1987 and 2000-2001); in both of the occasions the Bank provided the necessary liquidity to face the impressive stock markets slumps.[40] The Fed intervention when the asset prices bubble bursted is confirmed by what Greenspan claimed in the aftermath of the stock market crash in 2000:

> "The notion that a well-timed incremental tightening could have been calibrated to prevent the late 1990s bubble is almost surely an illusion. Instead, we noted in the previously cited mid-1999 congressional testimony the need to focus on policies to mitigate the fallout when it occurs and, hopefully, ease the transition to the next expansion" (Greenspan, 2004 p. 36).

This narrative evidence makes it plausible to endorse the hypothesis that the Fed actually changed its normal/official attitude of "benign neglect" vis-à-vis stock prices when the crashes occurred. Given the anecdotal evidence of a sudden monetary policy relaxation after any serious stock market crash, we have an acid test for the ability of our nonlinear method to capture switches of monetary policy across regimes.[41]

[38] According to Borio *et* al. (2003), during the 90s and the initial years of the new century CBs have been called to face the new challenge of defining how to incorporate severe boom and bust cycles in asset prices into the monetary policy framework. They argue that there exist two contradicting views on this regard, and no agreement has been reached yet. According to one view, the current economic environment is the natural extension of that prevailing during the inflationary period of the late 80s -early 90s. The set of strategic policy responses developed during the period of the fight against inflation remains a reliable benchmark because the most recent economic development is nothing but a series of unusual shocks, which are unlikely to occur again in the near future. This attitude is called the "continuity" view. In contrast with this view, Borio et al (2003) claim that the actual economic environment has deeply changed from the past. Financial markets liberalization, low rates of inflation, high credibility of central banks' anti-inflation commitment, and uncertainty about the degree of structural supply-side improvements have produced a totally new environment. The authors argue that in such a new context the achievement of price stability may be associated with an increasing risk of financial instability.

[39] Dekten and Smets (2004) claim that "Overall, the various linkages between asset prices, financial stability and monetary policy are complex because they are inherently nonlinear and involve extreme (tail probability) events. This implies that simple monetary policy rules may not be appropriate as a guide for monetary policy in such circumstances. Instead, monetary authorities must take a stance on the probability of such events and evaluate to what extent their actions may reduce this probability." (2004 p. 28). It follows that "a characterisation of optimal monetary policy becomes even more complicated when one allows for the probability that a rise in financial imbalances may results in a financial crisis with large negative effects on economic activity and price stability."(Dekten and Smets 2004, p. 8).

[40] In 1998, Chairman Greenspan noted that, "the stock market crash of late October 1987 shifted the balance of risks, and the Federal Reserve modified its approach to monetary policy accordingly. In particular took steps to ensure adequate liquidity in the financial system during the period of serious turmoil, and ... encourage some decline in short term interest rates."

[41] Despite our investigation having no direct predecessors in the literature, other papers have come to similar conclusions about the crucial importance of stock market crashes. Gerlach-Kristen (2004) uses a latent factor to pick those changes in the monetary policies that seem to be unrelated to inflation and output gap. She finds that the latent factor movements

As it results from the tests reported in Table 2, it is dsp_{t-1}, the asset prices related variable that performs best among the various transition candidates.[42] The estimates are reported in Table 4.

	Crash regime		*No crash regime*	
Coefficient	Estimate	St.error	Estimate	St.error
a	2.7080	1.0312**	2.0403	0.2858***
b_π			0.4720	0.0727***
b_y			0.1176	0.0319***
ω_{z1}	-0.7972	0.3054**	-0.3079	0.0804***
ω_{z2}			-0.4810	0.0783***
ρ_1	0.4985	0.1258***	0.9399	0.1099***
ρ_2			-0.2782	0.0796***
Model parameters:				
	Estimate		Standard error	
Speed of transition (γ)	7.5507		0.9341***	
Threshold (c)	-51.5956		6.8490***	
Summary statistics				
Sum of squared residuals	2.2870			
Akaike Info Criterion	-2.9340			

Table 4. LSTAR estimates, transition variable: dsp(t-1). Stock market crash case ($z_1$is the U.S. Treasury note spread and z_2 the BAA spread)

Also in this section, we focus exclusively on the augmented specification since it outperforms the non-augmented one both in the linear and in the nonlinear cases. The first interesting result is that the estimates of the no-crash regime do not differ much from the estimates of the linear augmented rule reported in Table 1. Instead, the estimates of the crash-regime indicate a change in the behaviour of the Fed. The usual indicators, inflation and output gap, seem not to play any role in setting the interest rate, while the BAA spread becomes more important and the smoothing decreases. This simple rule suggests that the Fed faced the stock market crash injecting liquidity and lessening the degree of history-dependence of the policy, as this approach was likely to be temporary.

This finding is reasonable and conveys the idea that linear Taylor-type rules detect the broad contours of monetary policy but fail to capture the specificities of the crash period: this was exactly the twofold hypothesis we aimed at testing with this work. The visual inspection of figures 6, 7, and 8, which refer to the specification in Table 4, confirms that hypothesis.

follow the occurrence of several special events. She notes that 'excessive loosening' has been practised in the period 2000-2001, that is after the burst of the IT bubble and September 11. Also D'agostino, Sala and Surico (2004) find a nonlinear behaviour of the FED using a TAR-SVAR model. Their analysis differs in several points from ours. They use monthly data, a TAR regime and an augmented Taylor rule in VAR framework. In addition, their analysis is set in terms of stock market volatility, although it turns out that asset price bursts are associated to the highest volatility periods. In the paper, the interest rate smoothing estimates are not reported and we cannot compare our results to theirs.

[42] The estimates associated with $ret1m_{t-1}$,$ret3m_t$ and $ret6m_t$ are also available upon request.

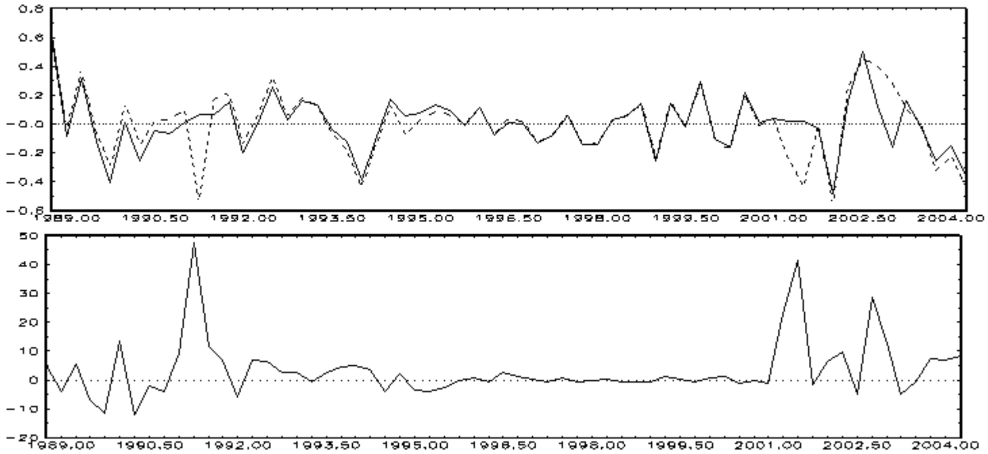

Figure 6. (UP) Residuals from linear (dashed) and nonlinear (solid) Taylor-type rule. Stock market crash case. (LOW) Difference squared linear and nonlinear residuals

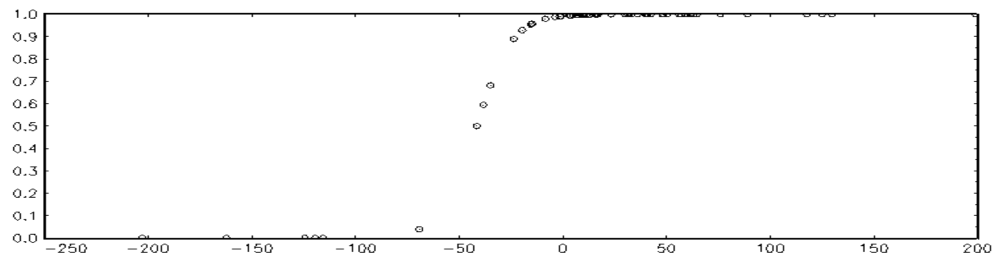

Figure 7. Transition function against transition variable (dsp_{t-1}) - Stock Market Crash case.

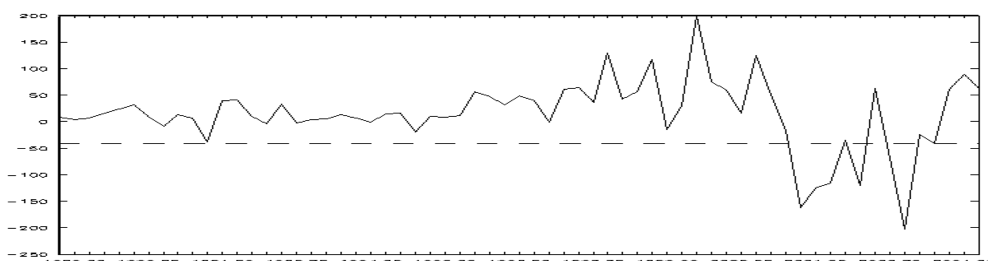

Figure 8. Transition variable (dsp_{t-1}) and threshold c- Stock Market Crash case.

If we observe the lower graph in figure 6, it is easy to see that the linear and nonlinear rules produce almost the same residuals during most of the 90s (the line is extremely close to 0), whereas the nonlinear specification performs better in the crashing period.

It can be shown that the estimates of the no-crash regime are robust in the face of changes in the transition variable[43] and in the specification of the crash-regime; in contrast, the crash-regime seems to be sensitive to the transition variable. Indeed, since $ret1m_{t-1}$ is also a valid candidate as a transition variable, we estimate the nonlinear model based on it. The estimation yields a threshold at zero and a crash-regime in which the Taylor-type rule collapses in a very persistent autoregressive process.

[43] The results are available upon request.

This last result makes the estimation of the crash-regime not completely satisfactory. The lack of robustness with respect to the choice of the transition variable and a rule which looks like an autoregressive process (we recall that this was also the case in the analysis of the ZLB) lead us to consider possible explanations. We focus on three main arguments. The first one proposes that only a few observations belong to the special regimes, the ZLB-regime and the crash-regime respectively. This makes it difficult to estimate the associated parameters and, in particular, the speed of transition γ. Unfortunately, there is no solution to such a problem since the number and the length of the crashing periods in the Greenspan era are given.[44] The second explanation we propose contemplates the possibility that the presence of a ZLB problem just after the crashing period may have affected the results. One way of solving this problem consists in cutting the sample so as to leave out the ZLB period.[45] This will also serve as test for the robustness of the results across different samples. The third and last explanation is that our rules lack those variables that actually informed policymakers in the special periods under investigation. The autoregressive specification of the crash and ZLB regimes might conceal an omitted variable problem, as much as we saw it did in the linear non-augmented case. It is important to notice that the estimates of the no-crash/no-ZLB regime are quite robust across the different specifications. This means that if some variables are omitted, they are correlated with the regressors of the crash/ZLB regime and not with those of the whole sample.[46]

In the light of the previous considerations, we repeat the estimation of the crash case after dropping the observations from 2002.2 onwards. The linearity test over this shorter sample suggests the same transition variables candidates we found in the full sample. The results are reported in Table 5.

[44] The alternative is to use monthly data. Most of the empirical literature on policy rule that is based on monthly data (see for instance Clarida et al., 2000) refers to forward looking specification of the rules and uses GMM or two stage least squares as estimation methods. Among others, one reason for doing so is that OLS estimations of contemporaneous or backward looking rules at monthly frequency produces estimates with hard economic interpretation. In addition, OLS models based on monthly data suffer of specification problems (see for instance the Kesriyeli et al., 2004) that make unreliable the test for nonlinearity required before proceeding to the STAR estimation. On the contrary, the IV approach gives reasonable estimates but at cost of quite arbitrary selection of the instruments that would blur the specific role of the variables, particularly the transition variable, in the nonlinear estimation. Lastly, since policy rules in the sense proposed by Taylor, and the associated stability conditions, are meant for quarterly frequency, we prefer to stick to quarterly data.

[45] Another possibility consists in adopting a multiple regime nonlinear model. In practice, this solution cannot be pursued because of the use of quarterly data and the short length of the different regimes.

[46] To account for the third possibility we acknowledge another explanatory variable that might have played some role in the periods under scrutiny. The additional variable we consider is the University of Michigan consumer sentiment index. The stock market crash usually translates into a sudden fall in consumer confidence which, in its turn, anticipates future reductions in household expenditures. If the central bank is concerned with the long lasting depressing effects of a market slump, this variable is a possible proxy of such central bank's worries. Despite its potential informative power, this variable is never significant in the specifications we estimate. For this reason, it does not appear in any of the specifications reported.

Sample 1988:3 2002:1

Transition variable	dsp(t-1)		ret1m(t-1)	
Coefficient	Estimate	St.error	Estimate	St.error
Crash regime				
a	15.9290	2.1673***	1.5004	0.2741***
b_π			0.4478	0.0887***
b_y			0.2507	0.0482***
ω_{z1}	-1.6038	0.10528***		
ω_{z2}	-3.3483	0.77067***	-0.6017	0.0955***
ρ_1			1.3090	0.1184***
ρ_2			-0.5783	0.0968***
NO-Crash regime				
a	2.1651	0.2590***	2.4997	0.3152***
b_π	0.5315	0.6689***	0.5734	0.0793***
b_y	0.1321	0.0295***	0.1237	0.0315***
ω_{z1}	-0.3292	0.0733***	-0.4137	0.0903***
ω_{z2}	-0.4824	0.0816***	-0.5160	0.0947***
ρ_1	0.8675	0.1096***	0.7280	0.1119***
ρ_2	-0.2473	0.0706***	-0.1563	0.0798*
Model parameters				
Speed of transition (γ)	19.2280	1.6972***	34.3197	1.6984***
Threshold (c)	-36.0690	1.7659***	0.1085	0.0858
Summary statistics				
Sum of squared residuals	1.5300		1.3394	
Akaike Info Criterion	-3.1450		-3.1690	

Table 5. LSTR estimates (sample 1988.3-2002.1). Stock market crash case. ($z_1$is the U.S. Treasury note spread and z_2 the BAA spread).

The estimates of the no-crash regime are quite similar across specification and pretty close to the linear Taylor-type rule. As in full sample case, the differences appear in the crash-regime estimates. When dsp_{t-1} is the transition, the CB stops smoothing and drastically reduces the interest rates. As in the previous estimation, the current output and inflation measures do not affect policy decisions as they were not able to provide information on what would happen in the economy without the intervention of the central bank. On the contrary, the weight on the Treasury note spread and the BAA spread, which can be seen as a measures of the investors' concerns about the future, strongly increases. These results are in line with the findings of the full sample estimation based on the same transition variable. The second specification in Table 5, where $ret1m_{t-1}$ is the transition variable, shows a threshold at zero and a crash-regime that is not dramatically different from the no-crash one. These results do not look consistent across sample, as the rule of the crash is completely different, and once again they are not robust to changes in the transition variable. In order to understand those findings, it is worth looking at the behaviour of the two transition variables and at the estimated thresholds. When $ret1m_{t-1}$ is the transition variable, the threshold is such that the regime associated to values below the threshold includes not only the period after 2000 (i.e. the crash we are interested in) but also other isolated episodes over the whole sample. Therefore, the estimated model detects a regime which includes temporary situations (1 observation each) in which the Bank reasonably did not change its behaviour, as it did during the crash-regime. Those situations are likely to average out the estimated response to the crash of the 2000-2001 and to veil the actual specification of the crash-regime. In contrast, when dsp_{t-1} is the transition variable, a clear slump is observable in correspondence of the crash and only the observations belonging to this period fall below the threshold. Following these facts, dsp_{t-1} is deemed to be a better indicator of the crash of the 2000-2001 and we should rely on the results associated with it.

To sum up, the Federal Reserve Bank seems to have modified its reaction function according to the negative developments of the stock markets. While linear Taylor-type rules seem to be able to catch the broad features of the decision-making process, they lack power in describing the central bank policy at the time of the market crash. For sure, if there exist situations that require central bankers to apply a special dose of judgment, a stock market crash is one of these and the results suggest that in those situations the usual indicators of monetary policy are temporarily put on the side. This is in line with the stress Svensson puts on the role of judgment in policymaking and with what Greenspan later on claimed:

> "During 2001, in the aftermath of the bursting of the bubble and the acts of terrorism in September 2001, the federal funds rate was lowered of $4.\frac{3}{4}$ percentage points.[...] We were able to be unusually aggressive in the initial stage of the recession of 2001 because both inflation and inflation expectations were low and stable" (Greenspan 2004, p. 36).

Taylor-type rules seem to fail if we employ them to describe the monetary policymaking. Rather, they should be used to provide the public with the broad contours of the monetary policy and by relaxing the linearity constraint they can be used as a practical benchmark to ex post detect the operating regimes.

6.2.2 The stock market boom (1994-2000)

As suggested above, the literature holds no conclusive answers about either the actual size of the asset prices bubble that grew from 1994 to 2000 in the US stock market, or the actual response of the policymakers in the face of it. It has been largely discussed whether the US central bank had changed its policy conduct in that period, and many wondered whether it would have been optimal to do so. More generally, a debate has recently flourished about whether and how monetary authorities should take into consideration the evolution of asset prices in policymaking.[47]

Despite the large number of contributions, a common position has not yet emerged. It is beyond the scope of this work to reproduce all the controversial findings and arguments disseminated in the literature. We believe that the very reasons for the contrasting conclusions of the various works can be traced back to the existence of two main problems: namely, the alleged existence of nonlinear relationships between asset prices and macroeconomic variables, and the fact that asset prices can be driven both by fundamental and non-fundamental forces, which are hardly distinguishable without the benefit of hindsight.[48] Furthermore, the debate about the relevance of asset prices in monetary policymaking has not been confined to the prescriptive realm. Many authors have empirically investigated whether and, (if yes), how central banks have actually taken into account asset prices while setting their policy instruments. Very different estimation techniques have been adopted to (*ex post*) detect the actual role played by asset prices in shaping monetary policy and, unsurprisingly, the conclusions reached are quite controversial too.[49]

[47] See, among others, Bernanke and Gertler (1999, 2001) and Cecchetti, Genberg, Lipsky and Wadhwani (2000).

[48] Indeed, the strikingly different conclusions diverse authors have developed stem from the various ways these two facts have been modelled in their works. See, for instance, Bernanke and Gertler (1999, 2001), Cecchetti et al (2000, 2002), Bordo and Jeanne (2002), Dekten and Smets (2004); Tetlow (2005), Borio and Lowe (2002), Gruen et al (2003), Bean (2004).

[49] See, for instance, Siklos et al. (2004), Chadha et al. (2003), Rigobon and Sack (2003).

Whereas the previous sections contained a rough analysis of what Greenspan asserted to have done, this section is devoted to testing a more speculative idea. He claimed that the U.S. monetary authorities almost neglected the growth of the stock market bubble in the late 90s (see his statement in the previous section). The exercise we undertake does not consider whether or not the Fed tried to burst the bubble, but rather how the monetary policy had been influenced (in any direction) by the booming stock market.

One could argue that our estimates in the previous section rule out the existence of a monetary regime associated to booming asset prices. However, this would not be totally correct. Our nonlinear estimates do suggest that the stock market crash in 2000 was the main source of nonlinear behaviour of the Fed, but they do not rule out the possibility that also booming asset prices had a nonlinear influence on monetary policymaking. The employed nonlinear Taylor-type rules reveal the existence of two regimes: a lower one corresponding to very negative stock returns, and an upper one related to positive and not very negative returns. Whether other finer regimes, corresponding to boom periods, exist, remains a possibility. Empirically, an STR model like the one employed here does not allow the detection of more than two regimes at a time. Therefore, from the estimation, we can at most conclude that the regime associated to market crashes is empirically more relevant than one possibly associated to market booms. In order to add a further regime driven by the same transition variable we would need to resort to a Multiple Regime STR model (MRSTR)[50]. Further research could be done along these lines, yet the size of the sample and the complexity of the techniques involved make it very hard to investigate this possibility.

The timing of the events in our sample, however, is of use. The ZLB and the stock market crash periods occur at the end of our sample. In order to exclude the overwhelming nonlinear effect of the stock market crash, a viable solution is to cut it from the sample: this can be done without loosing continuity in the data[51]. Accordingly, the following estimates differ from the previous ones in that they are conducted over a shorter period of time, precisely between 1988:3 - 2000:1.[52] Thus, focusing on this subsample, we explore whether the Fed changed its policy stance during the late 1990s according to the alleged US stock market bubble.

Due to the cut of the sample we need to update the linear estimation before testing the nonlinearity of the model. Furthermore, since we aim at isolating a bubble policy regime, we focus on different measures of stock returns and prices (and some lags) as candidate transition variables.

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[50] Admittedly, it could also be argued that there exist more than two regimes, associated with more than one transition variable. Extending the model to multiple regimes and multiple transition variables is even more difficult than moving to a multiple regime model with one transition variable. In addition this approach requires a very high number of observations, which could only be available through use of monthly data. We already discussed the shortcoming related to the change of frequency.

[51] Certainly, this restricts even further the degrees of freedom of the model and requires to take the results with a grain of salt and care.

[52] Indeed, in retrospect, the US stock market recorded the all-time high in March 2000, the peak of the bubble before the crash.

	Non augmented		Augmented			Non augmented	Augmented
Coefficient	Estimate	St. Error	Estimate	St. Error	*LR parameter*	Value	Value
a	0.4814	0.1407***	2.3712	0.2935***	c	2.4047	6.3742
b_π	0.2875	0.0832***	0.5014	0.0788***	$\beta\pi$	1.4362	1.3478
b_y	0.1734	0.0404***	0.1586	0.0338***	βy	0.8664	0.4262
ω_{z1}			-0.2772	0.0897***	$\beta z1$		-0.7450
ω_{z2}			-0.6194	0.1114***	$\beta z2$		-1.6651
ρ_1	1.3152	0.1133***	0.8663	0.1124***			
ρ_2	-0.5153	0.0975***	-0.2383	0.0799***			
	Summary statistics						
Sum of squared residuals	3.4765		1.7047				
Akaike IC	-2.3914		-3.0189				

Table 6. OLS estimates 1988.3-2000.1 (z_1 is the U.S. Treasury note spread and z_2 the BAA spread)

Table 6 shows the results of the two different linear specifications and reports also the long run parameters. The results of the regressions suggest that, also in this case, the augmented rule performs better than the standard one.[53]

We now proceed to test the nonlinearity of both of the specifications. However, since the aforementioned results suggest that the augmented version is more accurate as a model of reality, we will concentrate most of our attention on it.

		ret1m(t)	***ret1m(t-1)***	***ret1m(t-2)***	***ret3m(t)***	***ret3m(t-1)***	***ret3m(t-2)***	***ret6m(t)***	***ret6m(t-1)***	***ret6m(t-2)***
Non augmented	*F-test*	3.7661	2.3561	2.2478	2.9258	2.8402	1.1217	1.6469	1.6014	1.1312
	p-values	0.0013	0.0255	0.0324	0.0074	0.0088	0.3844	0.1258	0.1393	0.9851
Augmented	*F-test*	3.2951	1.8194	3.3332	1.7410	1.4949	2.3913	0.8013	1.3759	1.2734
	p-values	0.0057	0.0974	0.0054	0.1146	0.1912	0.0305	0.6902	0.2442	0.3002

		retma(t)	***retma(t-1)***	***retma(t-2)***	***dsp(t)***	***dsp(t-1)***	***disp(t-2)***
Non augmented	*F-test*	3.9834	0.1278	1.2956	0.7357	3.1320	2.0488
	p-values	0.0009	0.1278	0.2704	0.7295	0.0048	0.0508
Augmented	*F-test*	1.1735	1.9374	2.7430	0.8134	1.1269	1.7794
	p-values	0.3651	0.0763	0.0155	0.6785	0.3991	0.1058

Table 7. F-statistics and p-values of LM3 score tests for STR nonlinearity. Sample 1988.3-2000.1

A general overview of the tests (reproduced in Table 7) reveals that dsp (at all lags), which was an important indicator of the crash, does not appear to be a source of nonlinearity here, at least once the rule includes both z_1 and z_2. The same reasoning applies to $ret3m_{t-1}, ret6m$ (at first lag) and $retma_t$. These results deserve a few comments since they differ from those obtained over the longer period until 2004. The fact that we reject the hypothesis of nonlinearity in most of the augmented cases, whereas we cannot reject it while using the non-augmented version leads to two considerations. On the one hand, what drives the results of the tests of nonlinearity in the non-augmented version might be a problem of misspecification whereas on the other, if we compare these tests to those reported in Table 2, the importance of nonlinearity in the subperiod 1998:3-20001:1 is very limited or nil. This result alone is a prima facie evidence against the hypothesis that the Federal Reserve Bank had modified its reaction function facing an alleged stock market bubble, and this goes exactly in the direction suggested by Greenspan.

[53] In particular, as we have already observed in the case of the longer sample, the comparison of the residuals of the two models shows that the addition of the *ltst* and the *spread* improves the fit of the rule, especially during the late 1990s. We do not report the graphs that remain available on request.

We report the results of the LSTR estimations related to the transition variables with the lower p-values in the augmented form[54]. Therefore, we consider both $ret1m_t$ and $ret1m_{t-2}$ as potential transition variables. The results of the LSTAR estimations are very similar for both of the variables therefore we report only the results for the first one.

Sample 1988:3 2000:1				
	No bubble regime		*Bubble regime*	
Coefficient	Estimate	St.error	Estimate	St.error
a	1.8031	0.3219***	2.5640	0.4161***
b_π	0.4684	0.0858***		
b_y	0.2993	0.0392***	0.1315	0.0433***
ω_{z1}				
ω_{z2}	-0.6956	0.1475***	-1.2677	0.1974***
ρ_1	0.7188	0.0424***	0.9212	0.0381***
ρ_2				
Model parameters				
	Estimate		Standard error	
Speed of transition (γ)	109.6169		4.5056***	
Threshold (c)	0.8517		0.0154***	
Summary statistics				
Sum of squared residuals	2.2633			
Akaike Info Criterion	-2.5652			

Table 8. LSTAR estimates (Sample 1988.3-2000.1), transition variable *retm1.* Stock market boom case ($z_1$is the U.S. Treasury note spread and z_2 the BAA spread)

In both cases, the model exhibits instability in the specification. The threshold jumps from one extreme to the other of its observed range, passing from positive to negative, with very few isolated observations in one regime and all the rest in the other one.[55] This is a clear sign that the model is unable to identify two separate monetary policy regimes associated with the bubble phenomenon.

These findings do not contradict the results of the tests of nonlinearity. In fact, the LTSR estimation captures some movements in the Federal Found rate corresponding to extreme peaks of the transition variable that the linear model is not able to catch. Nonetheless, this is not enough to state the existence of two different regimes. Rather, the outcome suggests that there is no evidence of change in the policy stance of the Fed during the late 1990s. One could argue therefore, that Chairman Greenspan had done what he actually claimed to have done.[56] That is, little or nothing. It is commonly accepted that the Fed kept a tight monetary policy because of the concerns regarding the soaring stock prices. This may be the case, but such concerns were not driving remarkable changes in the policy approach.

To conclude, all these results suggest that in order to represent the Fed's behaviour from the 1988 to 2000, a linear augmented Taylor rule, including the BAA spread and the difference in

[54] For the sake of completeness, we have also estimated the nonlinear non-augmented specification with the transition variables associated to the lowest p-values. When the $retma_t$ is the transition variable, the two alleged regimes have very similar specifications, and the threshold leaves few isolated observations below. If the upper regime corresponds to the bubble regime, it seems to collect almost all observations. Yet, this cannot be the case, because few isolated observations do not constitute a regime. Using the $ret1m_t$, instead, the threshold is at the bound (necessary for the convergence) imposed by the technique: just one isolated observation is included in the alleged new regime. This suggests that if there were no bounds, a second regime would not have been found. If we consider dsp_{t-1}, the same sort of results is obtained. It is worth noting that none of the models above performs better than the linear augmented rule.

[55] Further estimations available upon request show this point in detail.

[56] It is possible that the monetary authorities tried to raise the interest rates in the booming period. This decision, however, does not constitute a "regime switch" as defined here. It rather refers to a discretionary, one-off move.

the long and short term government yields, gives better results than a standard non augmented and a nonlinear rule. Remarkably, this is particularly true for the last four years.

6.3 Discussion of the results

The technique we have used allows us to split the monetary policy conduct into several regimes covering the whole sample under scrutiny. Since we manage to identify regimes on a pairwise basis, we find that one regime is often short-lived and that it is driven by policymakers' economic considerations about events and contingencies (approximated by means of appropriate transition variables) and that the other covers the remaining period. The former can be seen as a "special regime", since it applies only in special circumstances, that is when policymakers change their policy conduct because of facing important events and contingencies. The non-special regime contains most of the observations in the sample and can be seen as either the "remaining average regime", or the "general regime". In effect, it depicts the broad features of monetary policy in all the periods other than those in the "special regime". Since most of the observations in the sample belong to the "general regime", the estimates of the "general regimes" in each of our cases proxy the coefficients of the linear Taylor specifications. The very reason why linear Taylor rules pick up the broad behaviour of the monetary policy over long periods of time is that individual "special regimes" are relatively short and thus average out. These regimes, however, are extremely important because it is in such special circumstances that policymakers disconnect the automatic pilot and use their judgment to make decisions. The linear specification, by imposing a unique constant regime over the entire sample, fails to take this point into account and misses all the policy decisions that correspond to finer policy regimes. It could be argued that we did not manage to disentangle all the finer regimes at the same time, and that we detected only one regime at the time. This is the reason why the "non-special" regime in each of our estimations is called the "remaining average regime" or the "general regime". Yet, the goal of the work was not to identify all the exact rules working in the finer regimes at the same time, for this would be hardly feasible. Given the available data and the features of the estimation technique, instead, we have shown the extreme fragility of the linear Taylor-type rules, the existence of finer policy regimes in correspondence of special circumstances, and the misleading conclusions that one could draw by relying on linear Taylor-type rules. It could be argued that what we call regime switch is, instead, a prolonged deviation of monetary policy from a "normal" behaviour, which is represented by the linear Taylor rule. However, if several regimes are present, it is not clear what an "average" linear rule stands for. We do not exclude the existence of the normal behaviour, however this has not to be necessarily the estimated linear Taylor rule.

As we argued above, while the "general regimes" estimates seem to be robust to changes in the transition variable and in the specification of the "special regimes", it is difficult to detect meaningful specifications for the rule in these "special regimes".

Since our methodology requires that we find an economic variable driving the transition across regimes, in order to identify all the actual monetary policy changes, we would need to employ as transition variables indicators that directly refer to the uncertainty and the risks that the policymakers perceive when they decide to keep or change the current monetary policy conduct. The choice of the transition variable is, therefore, very important and it would certainly be desirable to select indicators that provide an explicit measure of the policymakers' concerns over prospective contingencies. In the next section we discuss the appropriateness of the indicators used in this work.

7 The relevance of the transition variable

As discussed in the introduction, Greenspan claimed that changes in the monetary policy conduct are and should be undertaken according to the "judgment about the probabilities, costs and benefits of the various possible outcomes under alternative choices for policy" (Greenspan 2004 p.37). Since our methodology requires that we find an economic variable driving the transition across regimes, in order to identify all the actual monetary policy changes, we would need to employ as transition variables indicators that fully reflect the probabilities, the costs and the benefits of the outcome under an unchanged monetary policy regime. Such indicators should directly refer to the uncertainty and the risks that the policymakers perceive when they decide to keep or change the current monetary policy conduct. In what follows we will discuss the appropriateness of the indicators we have used in this work and we will also provide a few general comments regarding the relevance of choosing a correct transition variable when using this methodology.

It could be argued that the indicators employed in our empirical analysis do not directly measure the perceived consequences, risks and uncertainty connected to the contingencies mentioned by Greenspan (i.e. the risk of economic instability after the stock market crash and the risk of ZLB trap in 2002-3). The transition variables we used in the estimation could, indeed, be seen as mere measures of the economic events occurred in 2001 and 2002-3, and not necessarily as good indicators of the prospective contingencies.[57] Nonetheless, the employed transition variables capture well the actual switches in monetary policy conduct. Why is this so?

We argue that while it would certainly be desirable to choose indicators that offer an explicit measure of the policymakers' concerns over prospective contingencies, in order to detect actual policy regime switches in practice, it is possible to employ good proxies of them. When extreme events (i.e. a stock market crash) are the main determinants of future contingencies (i.e. financial and economic instability or deflation), they can themselves be used as indicators of the contingencies that policymakers worry about. In effect, there seems to be a strong (and intuitive) correlation between the occurrence of extreme events (that we identify as large differences of the transition variables from their critical thresholds) and the implicit risks for the future paths of the economy.[58] It is the exceptional nature and the size of these events that make them good proxies of the actual dangerous contingencies perceived by the policymakers as threatening the evolution of the economy. Accordingly, we will distinguish between event-indicators, as those adopted in this work as transition variables, and contingency-indicators, that more directly reflect the policymakers' risk-management considerations but are not available in practice. Nonetheless, as long as event-indicators adequately represent such contingency-indicators, they allow this methodology to capture the monetary policy regime switches.

In what follows, we will discuss some borderline cases, and, by means of some thought experiments, we will discuss their potential implications for our methodology. In particular, we will consider the consequences of i) the lack of extreme events correlated to monetary policy regime switches, ii) the presence of uncertain, rather than risky, contingencies, and iii) the choice of the transition variable among alternative and contrasting indicators.

[57] In the stock market burst case, for instance, it could be argued that negative changes in the stock market prices represent a measure of the worsened financial conditions occurred in 2001, but do not reveal the central bankers' concerns about the risks that subsequent contraction and deflation would have occurred, had they not changed policy conduct. Similarly, a low level of the interest rates *per se* can be judged as an ineffective indicator of ZLB risks, which, instead, also depends on the prospective inflation and production paths.

[58] For instance, very negative changes in the stock prices and very low level of interest rates seem to proxy, respectively, the risks of economic instability after the stock market crash in 2001 and the risks of falling into a ZLB trap in 2002-3.

A first speculative conjecture can be made in light of the observations above. It could be argued that there might exist a certain class of *risks* that, despite being able to cause changes in monetary conduct, are not associated with dramatic economic events. In such cases, event-indicators cannot be used as proxies for the contingencies, for no dramatic events occur at all. Imagine, for instance, that the Fed is concerned with the prospect of rapid growth of a particular economic variable, which is the unique determinant of a dangerous contingency. If the bank manages to control this variable, it does not undergo any dramatic change and, therefore, we cannot use it as an indicator to identify *ex-post* the regime switch. In order to empirically detect these more subtle types of policy switches with our methodology, it would be necessary to find (or build) indicators that truly reflect those concerns that induce policymakers to modify their conduct. Neither event-indicators nor contingency-indicators would be available.

A second borderline case occurs when policymakers face *uncertainty* about the prospective evolution of the economy. In such a case, even if dramatic events actually occur, policymakers may decide not to change their policy because they are not sure of the best strategy to pursue. According to Greenspan's account, this is likely to have happened in the case of the stock market bubble period. The monetary policymakers acknowledged the possible existence of a stock market bubble, yet chose not to react because they were not sure about the effects and the appropriateness of their intervention. In such a case, the fast and steady growth of the asset prices can be seen as a dramatic event, but it cannot portray the policymakers' cautious considerations. To put it bluntly, if uncertainty prevents policymakers from changing monetary policy conduct, no indicator is relevant because there is no policy regime switch. Interestingly, if we take Greenspan at his word, it would be of little utility to find a better indicator of the actual policymakers' concerns over the rasing bubble because the latter group did not engender any monetary policy regime switch. Any attempt to change the indicator so as to detect a switch that never occurred would, obviously, be in vain.

To conclude, we would like to tackle another thought experiment that regards a possibly relevant contingency we have not yet tested for. Let us consider the steady worsening of the external financial position of the US in the last years, and the two prospective contingencies associated with it, namely "hard landing" and "gradual adjustment". Some economists have argued that there exists a serious risk of "hard landing" for the US economy; others have asserted that the situation is sustainable and a "gradual adjustment" process is likely to occur. Greenspan seems to agree with the latter class of positions since has warned against over-emphasizing the possible dangers of such financial situation. Nonetheless, it is not fully clear whether the bank has ever changed its conduct because of concerns regarding such daunting external financial positions. For argument's sake, let us assume that the bank has indeed modified its conduct when the likelihood of a "hard landing" contingency has reached a certain level. According to the discussion above, in order to detect this policy regime switch with the proposed methodology, we would need to choose an indicator that subsumes the perceived risks of a "hard landing" contingency. Two possible indicators are available: the first one is the volume of the US net external debt, while the second one is the US long term yields on newly issued debt. The first measure is an event-indicator but it proxies the perceived risks of a "hard landing" contingency because the higher is the level of the debt, the sharper and the more likely is the impact of the expected adjustment. The second measure, which refers to a financial variable, is not an event-indicator and depends on the expectations that private and public investors have about the likelihood of a future market reversal.[59] In practice, the actual behaviour of these variables in the last months was very different: while

[59] It goes without saying that this latter indicator can be useful at the condition that market expectations are close to those of the central bank. We assume that this is the case.

the debt has grown relentlessly, the yields have almost remained unchanged (In passing, note that this seems to suggest that the markets are not too worried). It follows that variables performing so differently cannot be interchangeable indicators of the (assumed) change in the policy conduct. Taken for granted that a monetary policy regime switch occurred, the debt-indicator would probably lead to detection of the regime change. On the contrary, the yields-indicator would probably prevent this from being done.

This thought experiment shows the importance of choosing the correct indicators while trying to detect actual monetary policy changes using actual data and a nonlinear Taylor-type rule. Moreover, this example has a more subtle implication: it is possible not to detect an actual policy regime switch if the wrong indicator is adopted as a transition variable.[60] It is worth recalling that this is only an error Type II. An error Type I, that is finding a policy change where there is none, does not depend on the choice of the transition variable. Admittedly, another kind of error could occur. If the employed indicator that is thought proxying a certain contingency A also represents a different contingency B, we risk attributing the reason of an empirically detected regime switch to the wrong cause. The possibility of incurring such an interpretational error reinforces the importance of carefully choosing the indicator to employ.

8 Closing remarks

In this paper we estimate nonlinear Taylor-type rules for the US monetary policy over the last 17 years. In light of the performance of estimated linear Taylor-type rules and in view of narrative evidence, we investigate if monetary policy has followed a nonlinear behaviour and has differed across regimes. In our analysis, the identification and definition of a regime does not depend on its time length but, rather, on how much the course of monetary policy is affected by events and contingencies. We are aware of the difficulties entrenched in this approach. First, the shorter the regime, the more difficult is for existing econometric tools to detect it. Second, the more a regime depends on information that is difficult to extrapolate from available data, the more difficult is its identification. Nonetheless, we maintain this approach because we believe that finer monetary regimes matter in that events and contingencies, independently from their duration, are able to dramatically affect the evolution of the economy.

A first look at our results suggests that, while the Taylor rule describes the broad contours of the Fed's behaviour relatively well, the US monetary authorities have often been influenced by the occurrence of particular phenomena, such as the stock market collapse and the danger of falling into the ZLB trap. Building on this view, we argue that linear Taylor-type rules tend to hide important finer regimes. We support this conjecture by investigating regimes like the stock market crash or the ZLB danger by means of a nonlinear estimation method. Indeed, an important advantage of a nonlinear investigation, with respect to a linear one, is that it allows detection of medium size regimes, which are characterised by information contained in publicly available data. These regimes are sufficiently short to be diluted (and, therefore, missed) by a linear rule, but sufficiently long to be captured by a nonlinear one. On the basis of our results, we conclude that estimated linear reaction functions are averages of several finer regimes' rules: the descriptive power of the former fades directly with the variety of the occurring regimes. The results also suggest that the number of econometric-identifiable

[60] It is theoretically possible that we have failed to detect a monetary policy change in the booming stock market period because we chose an "imperfect" transition variable. That is to say that, if the growth of asset prices *per se* (that is a mere event) does not proxy the perceived risks and costs of a following market crash, using them as transition variable may lead to misleading conclusions. However, this reservation would only be valid as long as an actual regime change has occurred and this is at odds with market commentary and Greenspan's account of the Fed' stance.

regimes is probably less than the one actually occurring. Therefore, a nonlinear investigation is certainly an important step forward in identifying finer and finer regimes, yet it may still overlook some of them.[61]

Furthermore, it is worth highlighting that linear estimations are weighted averages of actual regimes' rules where the weights reflect only the length of the regimes, and not necessarily their actual relevance. This may be misleading since, in practice, one crucial determinant of the importance of a regime is the potential evolution that it may initiate in the economy. One could even argue that the utility from being able to describe monetary policy in such "normal" periods is very limited. In other words, if a linear Taylor-type rule helps understanding decisions made when everything is fine, then it explains what is already almost intelligible even without resorting to the rule. Accordingly, our findings seem to suggest that linear Taylor-type rules fail to explain what represents the most interesting aspect of monetary policy, namely, judgment.[62]

Furthermore, noticing that the number and variety of the regimes directly depend on the uncertainty in the economy that multiplies contingencies, our results suggest an inverse relation between the utility of Taylor-type rules and the uncertainty in the economy. Finally, adding a note concerning an open economy, to the extent that openness increases the exposure to uncertainty we expect the scope of these results to be even greater.

Thus, we propose a truly new way of looking at the descriptive properties of Taylor-type rules: it reflects the theoretical shortcomings of the Taylor rules, it includes the concept of judgment, and it still conserves some descriptive power for this popular tool of monetary policy analysis.

Summing up:

1. The nonlinear investigation shows that for the US the linear Taylor rule is a weighted average of at least three regimes ("general", crash and ZLB related), where the weights are the number of observations of any regime.

2. Thus, by induction, the outcome of a linear estimation can be seen as a weighted average of the various regimes taking place.

3. The nonlinear estimation we use can identify some of, but not all, the actual regimes. Indeed, a regime may be too short and/or it can be difficult to identify a times series that is able to portray the information characterizing such regime.

4. Taylor-type rules are unlikely to pick up the exact monetary policymaking decision process; their descriptive power declines with the uncertainty, i.e. number of contingencies in the economy. However, they preserve some of their utility. They provide some information about the policy conduct in "normal" times and, they can also be employed to investigate whether, when and why central banks have strayed away from their "standard" conduct.

[61] Other potential finer regimes that could have escaped from the medium sized meshes of the nonlinear investigation could be related to the 1998 liquidity crisis and September 11 terrorist attacks. As Greenspan (2004, p. 38) put it, this events "prompted the type of massive ease that as been the historic mandate of a central bank".

[62] Greenspan claimed that " In pursuing a risk management approach to policy, we must confront the fact that only a limited number or risks can be quantified with any confidence. [..] As a result, risk management often involves significant judgment on the part of policymakers, as we evaluate the risks of different events and the probability that our actions will alter those risks. For such judgment, policymakers have needed to reach beyond models to broader, thought less mathematically precise, hypotheses about how the world works." (Greenspan, 2004)

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A Appendix. Testing for nonlinearity

A.1 Properties of the logistic transition function

The logistic transition function exhibits the following properties:

i) $0 \leq G(l_t;\gamma,c) \leq 1$,

ii) $G(c;\gamma,c) = 0.5$,

iii) If $\gamma \longrightarrow \infty$, the change in $G(l_t;\gamma,c)$ from 0 to 1 is almost instantaneous at $l_t = c$ and therefore the logistic function tends to behave like the indicator function $I[l_t > c]$ of the two regimes. $G(l_t;\gamma,c)$ becomes a step function and a STR model collapses into a threshold model, nested in LSTR as a special case

iv) If $\gamma \longrightarrow 0, G(l_t;\gamma,c)$ becomes a constant (0.5) and $\gamma = 0$ makes the model a linear one.

A.2 Testing against LSTAR

Luukkonen, Saikkonen and Terasvirta (1988) propose estimating a first order Taylor approximation around $\gamma = 0$. The test using this form has little power when the constants $\phi_{1,0}$ and $\phi_{2,0}$ are different across regimes but the slope parameters not. This problem can be overcome by means of a third order Taylor approximation which looks like

$$\begin{aligned} T_3(l_t;\gamma,c) &= G(l_t;o,c) + \gamma\frac{\partial G(l_t;\gamma,c))}{\partial\gamma}\mid_{\gamma=0} + \frac{1}{6}\gamma^3\frac{\partial^3 G(l_t;\gamma,c))}{\partial\gamma^3}\mid_{\gamma=0} + R_3(l_t;\gamma,c) \\ &= \frac{1}{2} + \frac{1}{4}\gamma(l_t - c) + \frac{1}{48}\gamma^3(l_t-c)^3 + R_3(l_t;\gamma,c) \end{aligned} \tag{8}$$

Substituting $T_3(\cdot)$ for $G(\cdot)$ into the original model yields the auxiliary equation

$$y_t = \beta_0' x_t + \beta_1' x_t l_t + \beta_2' x_t l_t^2 + \beta_3' x_t l_t^3 + e_t \tag{9}$$

where $e_t = \varepsilon_t + (\phi_2 - \phi_1)' x_t R_3(l_t;\gamma,c)$. The null hypothesis of linearity is equivalent to $H_0'' : \beta_1 = \beta_2 = \beta_3 = 0$. This test is an LM-type test , called LM_3. LM_3 has a χ^2 distribution with 3(p+1) degrees of freedom.[63]. If the null H_0'' is rejected, we cannot reject the alternative

[63]**Specific cases**

a) A note of caution while using LM_1 and LM_3 should be added. If $l_t = y_{t-d}$ with d≤p, then the terms $\beta_{i,0} l_t^i$ for i=1,2,3 should be dropped from the auxiliary equation to avoid multicollinearity.

b) If the transition variable l_t is not included in x_t, then auxiliary equation can be simplified to a more parsimounious version of it which nonetheless allows to detect differences in $\phi_{1,0}$ and $\phi_{2,0}$ when $\phi_{1j} = \phi_{2j}$ for $j = 1,...,p$.

The economy auxiliary equation becomes

$$y_t = \beta_0' x_t + \beta_1' x_t l_t + \beta_{2,0}' l_t^2 + \beta_{3,0}' l_t^3 + e_t$$

and the null hypothesis $H_0'' : \beta_1 = 0$ and $\beta_{2,0} = \beta_{3,0} = 0$. The resulting test statistics is called LM_3^e and it is distributed as a χ^2 distribution with p+3 degrees of freedom.

c) If the transition variable $l_t = y_{t-d}$, a simplification can be operated equally by exploiting the fact that the only parameters informative about $\phi_{1,0}$ and $\phi_{2,0}$ are $\beta_{2,d}$ and $\beta_{3,d}$. The simplified, economy, auxiliary equation becomes

$$\begin{aligned} y_t &= \beta_0' x_t + \beta_1' x_t l_t + \beta_{2,d}' y_{t-d} l_t^2 + \beta_{3,d}' y_{t-d} l_t^3 + e_t \\ &= \beta_0' x_t + \beta_1' x_t l_t + \beta_{2,d}' l_t^3 + \beta_{3,d} l_t^4 + e_t \end{aligned}$$

The null becomes $H_0'' : \beta_1 = 0$ and $\beta_{2,d} = \beta_{3,d} = 0$.The LM_3^e in this case is distributed as a χ^2 distribution with p+3 degrees of freedom.

d) Consider now the case it is not clear which lag d of y_t should be employed as transition variable.

$$y_t = \beta_0' x_t + \sum_{i=1}^{p}\sum_{j=1}^{p}\beta_{i,j} y_{t-i} y_{t-j} + \sum_{i=1}^{p}\sum_{j=1}^{p}\psi_{i,j} y_{t-i} y_{t-j}^2 + \sum_{i=1}^{p}\sum_{j=1}^{p}\varsigma_{i,j} y_{t-i} y_{t-j}^3 + e_t$$

This is a LM_3 statistics with p(p + 1)/2 + 2p^2 degrees of freedom. (A simplified LM_1 statistics for this specific case of a nonlinear STR model. An LM_1 model corresponds to the first order Taylor expansion as

$$y_t = \beta_0' x_t + \beta_1' x_t l_t + e_t$$

A.3 LM versus F statistics

In small samples, F statistics can perform better than LM statistics and this applies to our sample we covers 17 years only. For both the LM and the F statistics, we estimate the linear model (and obtain the residuals $\widehat{\varepsilon}_t$) and the auxiliary equation (11) (and obtain the residuals $\widehat{e}_t$).

Calling $SSR_o = \sum_{t=1}^{T} \widehat{\varepsilon}_t^2$ and $SSR_1 = \sum_{t=1}^{T} \widehat{e}_t^2$,

$$LM_3 = \frac{T(SSR_0 - SSR_1)}{SSR_0} \tag{10}$$

distributed as a χ^2 with 3(p+1) degrees of freedom (p+1 is the number of regressors in the linear specification) and

$$F = \frac{(SSR_0 - SSR_1)/3(p+1)}{SSR1/T - 4(p+1)} \tag{11}$$

distributed as a F-statistics with 3(p+1) and T-4(p+1) degrees of freedom. The null hypothesis of the various tests do not change and we do not repeat them here.

B Appendix. The modelling cycle

In what follows we briefly describe the procedure (that, as suggested by Granger (1993), is recommended to be specific-to-general) that is to be followed in nonlinear modelling. We list below the specific steps for modelling and estimating a nonlinear STR model.

1. Specify a linear model and choose the correct number of lags (in the case of an autoregressive process). Since the STR models require that the error terms are no autocorrelated, this first step of the modelling process is particularly important.[64]

2. Once an acceptable linear specification is obtained, test the null hypothesis of linearity against the alternative of (STR) nonlinearity. While this test does not require (at this stage) the choice of a specific functional form for $G(\cdot)$, the most appropriate functional form can be chosen afterwards on the basis of the results of the nonlinearity tests. Repeat this test for all the possible candidate to be a transition variables.

3. If the linear model is rejected, choose the most appropriate transition variable among the possible candidates (and among lags of the candidates) according to a statistical criterion as AIC or the p-values of the LM tests.

4. On the basis of the tests above and according to economic reasoning, choose the most appropriate functional form for $G(\cdot)$.

would have p(p+1)/2 d.f.). Note that the cross products have to be for $i \neq j$ in order to avoid perfect multicollinareity. This test is a general test of non-linearity.

[64] Often the rejection of linearity stems from the misspecification. of the functional linear form; such a finding should suggest the researcher to inspect the linear representation with classical tests and, if necessary, to apply the opportune modifications

5. Estimate the parameters of the STR model by a quasi-maximum likelihood technique.

6. Evaluate the model using appropriate diagnostic tests, recalling that only a few test statistics maintain their asymptotic distribution and their validity in a nonlinear environment.

7. On the basis of the tests' result, change the model where necessary. Repeat the steps 2, 3, 4, 5 if either further nonlinearity or parameter instability is detected and requires additional modelling.

C Appendix. Possible rationales of interest rate smoothing.

There exists a long series of plausible reasons why CBs prefer to smooth interest rates[65]. We focus on this theoretical point because it is crucial to understanding the motivations for the specific functional form we estimate. There are at least three different classes of motivation for central banks' interest rates smoothing behaviour. The first class of explanations reflects the idea that interest smoothing increases the effectiveness and the optimality of the monetary policy.[66] The second school of thought develops the idea that financial markets dislike interest rate volatility[67]. Banks, in particular, are often exposed to and severely affected by abrupt changes in interest rates[68]. Finally, the third class of explanations turns around CBs' reputation-building processes and communication strategies[69]. In addition to all these theoretical explanations, it is worth quoting Blinder who, while he was still vice-president of the Fed, admitted that "..a little stodginess at the central bank is entirely appropriate" (1995, p. 13). Without digging into the specific pros and cons of these explanations, it is appropriate to conclude that the interest smoothing component in the Taylor rule can be more than an ad-hoc addition to empirical estimated rules. Indeed, it is likely to subsume a series of central banks' concerns and worries, which a classical rule would not be able to capture.[70]

[65] For an overview, see Lowe and Ellis (1997), Rudebusch (2002), and Gerlach-Kristen (2004).

[66] Woodford (2001, 2003) claims that some interest rate smoothing is desirable because it allows discretionary monetary policy equilibrium to approximate the superior commitment equilibrium. Adding interest rate smoothing among the targets of the bank may result in "history dependent central-bank behaviour which, when anticipated by the private sector, can serve the bank's stabilization objectives through the effects upon current outcomes of anticipated future policy." (Woodford 2003 pp.861-862). Amato and Laubach (1999), among other authors, support the view that interest smoothing makes decisions more predictable, which, in turn, increases policy effectiveness. A different argument is made by Orphanides (1998), Rudebusch (2001), Sack and Wieland (2000), who maintain that real time data are often non-accurate and CBs prefer to be relatively cautious. Aoki (2003) raises the issue of noisy indicators for the variables and argues in favour of monetary policy cautiousness.

[67] Volatile short-term interest rates induce high volatility in all the other financial assets and affect discounting.

[68] Goodfriend (1987) and Cuckierman (1996) claim that CBs dislike frequent reversions of interest rates to reduce the systemic risks linked to the banking exposure and the volatility in the financial markets. Goodfriend (1991), Rudebusch(1995), Roley and Sellon (1995) and Levin, Wieland, and Williams (1999) argue that little short-term interest rate volatility guarantees the CB acquires a better control over long run bond yields, and, therefore, on the whole economy. (Admittedly, it could be argues that, this line of argument does not differ in substance from Woodford (2003)'s history dependence). Lowe and Ellis (1997) maintain that the authorities dislike the costs associate to repeated interest rate reversals. According to Bullard and Schaling (2002), the volatility of the asset prices in the financial markets depends, among other factors, on the volatility of the short-term interest rates via no-abitrage relationships. It could be argued that, if the CB has a preference for financial stability, a certain degree of interest rates smoothing could be intentionally aimed at containing volatility.

[69] Caplin and Leahy (1997), and Goodhart (1999) argue that frequent decisional changes may give the impression of indecision on the part of the CB. Lowe and Ellis (1997), Kuttner (2001), and Goodfriend (1991) observe that the announcement effect is bigger when the change is considered persistent, that is when there is a certain amount of inertia in the rates.

[70] Admittedly, Svensson (2003 pp.462-3) does not sympathise with most of the motivations illustrated. He is not fully convinced by the arguments that could fall into the second and the third classes above. Moreover, he claims that the relevance of history dependence (i.e. the first class above) is not established, and, even if history dependence actually matters, "a commitment to an optimal specific targeting rule is a more direct way of achieving such history-dependence."(2003 p. 462). The latter sounds as a rather prescriptive claim that, despite relevant, does not exclude the Federal Reserve Bank has actually tried to smooth the changes in the interest rates in the last 17 years.

Appendix. Diagnostic analysis

At the end of any nonlinear estimation, diagnostic tests for serial correlation, remaining nonlinearity and parameter constancy are usually performed. The following tables contain the p-values associated with these various test-statistics. The null hypothesis of each test is the lack of serial correlation in the residuals, the absence of additional nonlinearity, and parameter constancy. We produce the results for the main specifications considered in the paper.

The tests for residual serial correlation fail to reject the null hypothesis of no residual correlation in almost all the specifications. The bubble case is the only exception. The presence of serial correlation in the residuals suggests that the nonlinear model is not satisfactory, as it was already argued in the paper on the basis of the previous results.

The second diagnostic test considers time as an alleged second transition variable[71]. This is a test against a Time-Varying STAR model, which allows for both nonlinear dynamics and time-varying parameters. In practice, it tests parameter constancy against the alternative of smoothly changing parameters in the two-regime STAR model. In most of the cases, the results lead to reject the null hypothesis of parameter constancy. This would suggest the possible existence of a further regime, which has time as a transition variable. However, we recall that, in the initial tests, the variable time already seemed to be a plausible transition variable but the associated estimation was meaningless. Therefore, although reporting the result of this test, we suggest not overestimating its implications.

Lastly, we test the models for remaining nonlinearity. The null hypothesis of no additional nonlinearity can often be rejected. This result depends on the specification of the model and on the choice of the transition candidates. We believe that this finding is in line with the analysis previously conducted. Indeed, although different regimes (such as ZLB and crash) have probably coexisted in the long period considered, in each estimation we manage to deal only with one of them at a time. Therefore, it is not surprising to find that in the stock market crash case, for instance, there is some evidence of remaining nonlinearity in the interest rate, we had not dealt with. This reasoning is confirmed by the fact that, when we reduce the sample so as to focus on the bubble, we eliminate the observations associated to two of the three identified regimes (which cluster in the last part of the sample), and remaining nonlinearity is largely rejected[72].

To conclude, the results of the diagnostic tests seem in line with our previous findings. There seems to be strong evidence that at least three monetary regimes have characterised the Fed's monetary policy over the 17 years under investigation. While we cannot exclude that other finer, smaller and shorter regimes are equally present, the power of the diagnostic tests and the limited number of observations do not allow a more subtle analysis.

[71] The three LM specifications refer to the first, the second and the third order Taylor approximation of the transition function.

[72] Admittedly, the null hypothesis of no additional non linearity can be rejected only when ffr(-1) is the transition candidate. This is consistent with the results found for the ZLB case. In the period 1993-1995, the interest rate is quite low and flat. Although there is no evident risk of falling into a ZLB trap, the interest rates seem to behave quite oddly. This could plausibly be the reason why we fail to reject additional nonlinearity connected to ffr(-1) found in the diagnostic tests for all the sample periods.

	ZLB Augmented				**CRASH**. Augmented, transition dsp(t-1)			
	Serial correlation				Serial correlation			
Order	1	2	3	4	1	2	3	4
p-value	0.1718	0.5421	0.1944	0.339	0.1625	0.3882	0.1237	0.0986
Parameter constancy								
	LMc1	LMc2	LMc3		LMc1	LMc2	LMc3	
p-value	0.001	0.0004	0.0025		0.0599	0.0000	0.0000	
Remaining nonlinearity								
Transition	Quadratic term (p-value)				Quadratic term (p-value)			
ret1m	0.6107				0.0834			
ret1m(-1)	0.1218				0.3296			
ret1m(-2)	0.0037				0.0525			
retm3m	0.3091				0.0438			
ret3m(-1)	0.0073				0.6055			
ret3m(-2)	0.0117				0.8420			
retma	0.1443				0.5063			
retma(-1)	0.0465				0.2446			
retma(-2)	0.0021				0.0910			
ret6m	0.1805				0.3714			
ret6m(-1)	0.0049				0.9660			
ret6m(-2)	0.0371				0.0357			
dsp	0.0428				0.0000			
dsp(-1)	0.1075				0.0000			

Table A1. Diagnostic tests for ZLB and Stock Market Crash estimations. Full sample.

CRASH	Augmented,transition dsp(-1)				Augmented, transition ret1m(-1)				**BUBBLE**	Augmented, transition ret1m(t)			
1988.3-2002.1	Serial correlation				Serial correlation				**1988.3-2000.1**	Serial correlation			
Order	1	2	3	4	1	2	3	4	Order	1	2	3	4
p-value	0.1566	0.3699	0.1380	0.0891	0.0227	0.4346	0.1950	0.0813	p-value	0.0137	0.0222	0.0205	0.0201
Parameter constancy													
	LMc1	LMc2	LMc3		LMc1	LMc2	LMc3			LMc1	LMc2	LMc3	
p-value	0.4478	0.0013	0.0014		0.1921	0.0334	0.3213		p-value	0.0029	0.0000	0.0025	
Remaining nonlinearity													
Transition varioable	Quadratic term (p-value)				Quadratic term (p-value)				Transition variable	Quadratic term (p-value)			
ret1m	0.1310				0.1854				ret1m	0.1745			
ret1m(-1)	0.5511				0.0673				ret1m(-1)	0.6749			
ret1m(-2)	0.6913				0.0285				ret1m(-2)	0.7902			
retm3m	0.1239				0.0205				retm3m	0.2174			
ret3m(-1)	0.4807				0.6219				ret3m(-1)	0.3082			
ret3m(-2)	0.3785				0.2297				ret3m(-2)	0.3441			
retma	0.6748				0.7905				retma	0.2117			
retma(-1)	0.0543				0.6899				retma(-1)	0.0053			
retma(-2)	0.0110				0.1805				retma(-2)	0.0096			
ret6m	0.6722				0.5977				ret6m	0.1898			
ret6m(-1)	0.4151				0.1335				ret6m(-1)	0.3487			
ret6m(-2)	0.0069				0.0782				ret6m(-2)	0.0066			
ffr(-1)	0.0000				0.0000				ffr(-1)	0.0000			
ffr(-2)	0.0000				0.0000				ffr(-2)	0.0077			
									dsp	0.5800			
									dsp(-1)	0.3278			

Table A2. Diagnostic tests for Stock Market Crash estimations (sample 1988.3-2002.1) and Stock Market Boom estimation (sample 1988.3-2001.1)