Règles de Taylor et liquidité dans les marchés financiers

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Nous revisitons l'histoire de la politique monétaire américaine dans le cadre d'une règle de Taylor, en utilisant des données en temps réel. Nous constatons une instabilité importante des paramètres de la fonction de réaction de la Federal Reserve à l'écart de production et aux esperances d'inflation. Motivés par la crise financière mondiale et l'attention croissante portée aux marchés financiers, nous étudions le rôle de la liquidité dans la règle des taux d'intérêt. Nous estimons les modèles de commutation de Markov et constatons la conformité au principe de Taylor pendant la période d'inflation élevée pour une règle de Taylor standard et des violations cohérentes du principe de Taylor une fois que nous avons inclus des procurations pour la liquidité. Ces violations ne sont pas associées à des périodes d'inflation non ancrée.

Taylor Rules and liquidity in financial markets

We revisit the US monetary policy history in the framework of a Taylor Rule, using real time data. We find significant instability in the parameters of the Federal Reserve reaction function to output gap and expected inflation. Motivated by the Global Financial Crisis and the growing attention to financial markets, we study the role of liquidity in the interest rate rule. We estimate Markov Switching models and find compliance to the Taylor Principle during the high inflation period for a standard Taylor rule and consistent violations of the Taylor principle once we include proxies for liquidity. Such violations are not associated to periods of unanchored inflation.

Keywords: monetary policy rules, financial liquidity, Markov switching models, real-time data; règles de politique monetaire, liquidité financière, modèles de Markov, données en temps réel

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1 INTRODUCTION

In the decades prior to the 2008 Global Financial Crisis macroeconomic theory and monetary policy analysis had achieved a consensus on how to model macroeconomic fluctuations and their stabilisation. This corpus was developed around the core of the New Keynesian Dynamic Stochastic General Equilibrium models (NKDSGE) and their rich set of extensions. This class of models includes a Central Bank that typically acts in accordance to a Taylor [1993]-type policy rule: it aims at stabilising inflation and output by adjusting the interest rate in reaction to expected inflation and deviations from equilibrium output. Despite criticism, this class of models rose to a prominent position in the central banking tool-kit and informed policy decisions, thanks to its empirical successes and theoretical attractiveness [Woodford, 2003; Gali, 2015; Walsh, 2003].

Against this backdrop, we investigate whether the US Federal Reserve Bank acted consistently with such models, specifically with the prescriptions of the Taylor policy rule. We assume that the Fed reads the US economy through the lenses of a standard NKDSGE model and, first off, test whether it followed and complied to a standard Taylor [1993] rule. Second, we study how financial factors influence the Fed's policy-making. Our main contribution is to combine a Markov-Switching approach to estimate the Fed's reaction function with the inclusion of financial liquidity variables. This sheds light on the behaviour of the Central Bank and its dynamic response to economic and financial conditions.

The central tenet for a Taylor policy rule is encapsulated in the so-called Taylor principle, which implies that the monetary authority reacts more than one-to-one to expected inflation through its policy interest rate. In theoretical models, this rules out indeterminacy of equilibria, in which inflation follows a totally arbitrary (implausible) paths[2].

This generally accepted feature became problematic in light of the Zero Lower Bound period (2008Q4-2015Q4), during which the policy interest rate did not react at all to inflation expectations. Over this period, the Fed implemented a number of non standard policies (Quantitative Easing, QE), addressing disruptions in the financial markets and contagion to the real economy. Interestingly, in spite of the violation of the Taylor Principle, inflation did not show an erratic behaviour as implied by workhorse NKDSGEs [Cochrane, 2018]. In fact, it hovered close to previous levels as shown in Fig.(1). The assumption in NKDSGEs that the policy interest rate is es-

[2] This restrictions is rooted in the requirements for unique solutions for the system of dynamic equations resulting from NKDSGE core 3-equation structure – IS Curve, TR, Phillips Curve.

sentially an interest on a pure, illiquid, bond came to appear at odds with actual policies and practices.

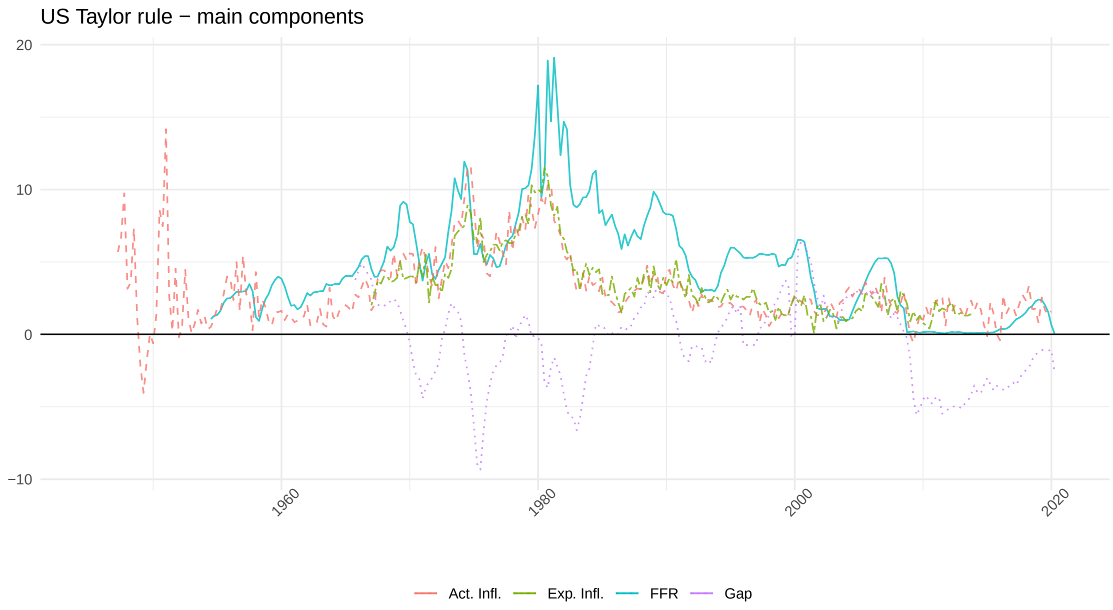

Figure 1: *Variables employed in the estimates. Historically revised GDP deflator (Act. Infl., dashed); Greenbook one-quarter GDP deflator forecast (Exp. Infl., dot-dashed); Federal Fund Rate (FFR, solid); Greenbook estimated output gap (Gap, dotted).*

On the basis of such policy innovations, we investigate whether Taylor-type rules can effectively accommodate financial and liquidity considerations, as suggested by leaning-against-the-wind literature [Svensson, 2017b] and, most importantly, the large body of post-GFC contributions [Calvo, 2016; Hall and Reis, 2016; Diba and Loisel, 2017].

This inquiry is motivated by the unconventional tools employed by major central banks in the aftermath of the GFC. In December 2008, upon hitting the ZLB on the Federal Fund Rate, the Fed rolled out a growing set of QE policies, *de facto* liquidity facilities. These policies aimed at restoring liquidity and reviving several segments of the financial market, frozen by the recent financial turmoil[3]. Thus, when the interest rate policy tool turned into a loose cannon, liquidity management was elected as major policy strategy. In light of these events, we augment a standard specification of the Taylor

[3]Federal Reserve Bank [2016e,f,d,a,c,b] programs descriptions all heavily stress liquidity concerns behind the implementation of each policy.

rule with financial and liquidity proxies to test whether the Fed has paid attention to such factors in its policy-making over the past 47 years.

In summary, we find that a traditional specification of the monetary policy reaction function does not fully account for the Fed's behaviour over the post-WWII period. When we include proxies for liquidity, we find regimes in which the Fed lowers the weight of expected inflation, while giving more weight to financial liquidity as defined in our study. We measure liquidity in the financial system as the spread between risk-free liquid assets and less liquid assets. We find that financial conditions affect the monetary policy conduct of the Fed. Indeed, the Fed consistently deviates from the Taylor Principle when financial liquidity is included in the Taylor rule. Moreover, we report instability in the policy rule and therefore investigate the presence of multiple regimes. In contrast with previous studies, when we consider a standard Taylor rule with real time data, we do not find deviations from the TP even in periods of high inflation.

To the best of our knowledge, our contribution is the first attempt to estimate the properties of a Taylor rule in an environment in which liquidity of assets play a role. Our interest focuses on reproducing as closely as possible the information set available to the Fed at the time of the decision and include liquidity proxies that sufficiently capture the dynamics in the financial market and its liquidity.

We contribute and relate to a vast literature. On the empirical branch we confront the exogenous regime definition of Clarida et al. [2000]. We also preferably use real-time data, whose importance has been shown by Orphanides [2001, 2004]. In studying how the monetary policy rule has evolved over time we consider the insights from Primiceri [2005]; Boivin [2006]; Canova and Sala [2009]; Sullivan [2016], and finally follow Murray et al. [2015]; Sims and Zha [2006]; Davig and Leeper [2011, 2006] in adopting a Markov Switching model approach to let the data speak as freely as possible under bare-bones restrictions. State-dependent policy rules have been studied and explored: estimated DSGEs like Bianchi [2013] model the Fed as switching between hawk (strongly anti-inflationary) and dove (weakly anti-inflationary) regimes and study the changes in regimes since WWII and their interplay with agents beliefs. Lhuissier [2018]; Lhuissier and Tripier [2019] employ Bayesian Markov-Switching methods to study volatility and uncertainty changes and their interplay with credit and financial frictions. Closely related is Levieuge [2002], who studies the relevance of a set of financial indexes in US, German, and Japanese monetary policy, and finds no role for share indexes. Concerning the specifications we utilise to look at the data, we also consider the contributions on leaning against the wind policies (LAW, see Svensson [2017a,b]) as comprehensive references, although this avenue is outside the scope of this work. On the other hand, we relate to works that analyse official reports and documents to assess whether the Fed takes into account financial factors. Peek et al. [2016]; Oet and Lyytinen [2017] find that discussing financial stability in FOMC meetings affects policy decisions, Wischnewsky et al. [2019] reinforces this evidence analysing congressional hearings of Fed Chairmen.

The paper is structured as follows. Section 2 presents the data set we compile; Section 3 presents the specifications we estimate, with results for the full sample analysis and the exogenous sub-sampling ones; Section 4 presents stability tests on the specifications that motivate a Markov Switching model estimation. Section 5 concludes the paper.

2 DATA

To investigate the US monetary policy conduct, we build a database of the most relevant time series on the US economy aggregates. Such database includes historical and real time data at the macroeconomic level, as well as statistics from specific micro-economic data to account for expectations. We collect data on inflation, interest rates, real economic activity, monetary aggregates, government debt and deficit, financial market indicators, and finally (measures of) expectations of these variables. In addition, we also collect and test two prominent synthetic shadow rates produced by Wu and Xia [2016] and Krippner [2015][4].

For each of these aggregates, we collect a set of more specific measures that differ in the exact definition or computation: the clearest examples are the GDP deflator, the CPI, and the CPE for inflation, or the capacity utilisation, lay-off rate, unemployment, and Fed's own calculations for the output gap. A side contribution of this paper is to provide a comprehensive and harmonised database as well as the tools to maintain, fine-tune, and customise it. This database is freely available on the author's website and upon request.

To obtain real-time data and distributions on agents' expectations, we source micro-data from the Greenbook data-set on forecasts and expectations, as well as the University of Michigan Survey of Consumers. The former includes the Survey of the Professional Forecasters, which provides expectations on economic aggregates at several time horizons. For financial variables, we employ two measures: the quarterly returns of the S&P 500 index and

[4] The related results are not included as they do not add any further insight to our analysis. They are used as robustness checks, though.

the weighted average return of BAA corporate bonds. These series are then transformed and used as proxies for the liquidity conditions in the economy.

The vast majority of the series are retrieved from the Federal Reserves of St. Louis and Philadelphia: a complete list is provided in the Appendix, Table (8) alongside with plots of the time series[5].

For a subset of the data we perform some transformations and manipulations to isolate precise information. We briefly introduce the transformed data below.

Output gap We collect several different measures of output slack, among which two are worth detailing. First, official output gap nowcast: this extrapolation uses data from the Greenbook database on the real time estimates on the GDP level and implements the methodology mentioned in Murray et al. [2015]. For each available date t, we regress the time series against a quadratic time trend and finally take the residual of the latest available data point, ε_t, as output gap observation for date t. We label the resulting time series as *real time output gap*[6]. It is closer to the signal policy-makers receive at the time of the decision. Thus this series is preferred and employed in the analyses of this paper.

Secondly, we compute the percentage difference between installed capacity and actual GDP, both provided by St. Louis Fed. We call this series *ex post output gap* since it relies on historical, revised data, not necessarily those available to policy makers at the time of their contingent decisions.

All measures are intended to encompass the advances in the related literature, including contributions such as Boivin [2006]; Gali and Gertler [1999]; Benhabib et al. [2001]; Cochrane [2011]; Gali et al. [2001]; Bilbiie and Straub [2013]; Orphanides [2001, 2004], among others.

The database also presents series on lay-offs, deviations from natural unemployment level and other related proxies for economic cycles.

Inflation and expectations Concerning the measures of inflation, we include revised time series like the indexes of GDP deflator, the Consumer Price Index (CPI), and the Personal Consumption Expenditure (PCE). For the last two, we also include two restricted versions excluding food and energy prices, dubbed Core CPI and PCELFE.

[5]The resulting data set, as well as the code to compile and maintain it, are available in this Git repository. The code itself might undergo significant improvement and extension over time.

[6]Further details are presented in the Data Appendix (B.1).

The Greenbook database from the Philadelphia Fed provides information on last, current and future expected values for three of the aforementioned indexes – CPI, PCE, and GDP deflator. In particular, forecasts are available up to eight quarters ahead from time t. The same database also offers now-casts on t and $t-1$ value of these variables. These expectations are part of the information set of the policy-maker at the time of decision and thus represent a reliable tool to gauge the policy rule. These data offer the opportunity to test monetary policy rule with different horizons of expectations, which in itself represents an interesting exercise to assess effects of forward guidance policies.

Liquidity proxies and financial indexes After the financial market collapse that triggered the 2008 GFC, liquidity gained momentum as research topic (alongside with safe assets and thus risk) especially following massive injections carried out by the Federal Reserve[7].

We employ the financial condition of the economy to infer underlying liquidity. Financial market prices embody a great deal of different information, so the risk of picking up the wrong signal or incur in endogeneity is high. Considering these threats we compute our indicators as premia over safe assets of comparable maturity, which are subject to "fire-purchases" in times of uncertainty or financial turmoil.

On this ground, we proxy liquidity in financial markets with two spreads. The first one is the difference between the Standard & Poor 500 quarterly returns and the 3-month Treasury Bill, the second is the gap between the weighted average yield of BAA corporate bonds (as provided by Moody's) and the US 10-year Treasury note.

Safety and *liquidity* of any given asset are intimately linked: safety concerns the discrepancy between face value and gross return *at maturity*, while liquidity characterises the difference between face value and *realised selling price*. Thus, the main difference between these concepts boils down to the timing difference. It follows that comparing any asset with its safest equivalent of appropriate maturity isolates its liquidity properties, at least theoretically.

With real data, liquidity and safety are more arduous to tell apart in a clear-cut way, especially at a macroeconomic scale. We thus proxy liquidity with spreads that isolate as much as possible the liquidity component of

[7]See among others Caballero et al. [2016]; Canzoneri et al. [2008b,a]; Canzoneri and Diba [2005]; Hall and Reis [2016]; Caballero et al. [2017]; Del Negro et al. [2017] for summaries and examples.

assets. Comparing safe assets with widely traded and riskier ones helps minimising the confounding of risk and liquidity, especially since we consider aggregate indexes rather than individual assets. This last factor is relevant as diversification forces operate already to drive down the risk component of our observables.

The intuition goes as follows: prior to a recession or slowdown in economic activity, publicly traded assets are fully liquid and smoothly traded. When uncertainty kicks in or expectations turn pessimistic, these assets become second choice to more reliable, safer assets. Agents on the market readjust their portfolios to shield from possible effects of the incoming downturn. As they sell these second-choice assets and shelter with Treasuries, selling prices of stocks and BAA bonds decrease (therefore pushing up expected return), whilst safe assets prices increase (and return plummets, possibly turning negative, too) as they maintain their attractiveness and liquidity. In this process, selling parties are willing to bear losses with respect to face value upon transaction, while stomaching increased prices to buy safer assets. Referring back to liquidity definition above, this dynamics mirrors a liquidity dry-up for second choice assets that percolates into relative yields. Therefore, the spread between the former and the latter factors reflects variation in liquidity of assets triggered by movements in market expectations.

We include these spreads in the decision rule of the Central Bank in order to test whether policy makers are also attentive to financial and liquidity conditions in the economy when setting their policies.

Throughout the rest of the paper we use the GDP deflator as the measure of inflation, since it maps closely the price dynamics emerging from the US economy. Moreover, its time series is the longest and affords estimation in the pre-Volcker period. To reproduce the information set of the Fed, we use our real time output gap measure. Both series strongly correlate with the alternatives and bear little differences in trends.

For completeness, Tables (10) in the Appendix presents correlations among selected variables in our data set over the period from 1986Q1 to 2013Q4, when all series overlap. Fig.(2) plots together all variables.

3 EMPIRICAL RESULTS

There is a broad consensus on the empirical validity of the Taylor rule, the more so since Volcker's chairmanship. At the beginning of his term he induced a switch in policy from a regime of indeterminacy (accommodative pol-

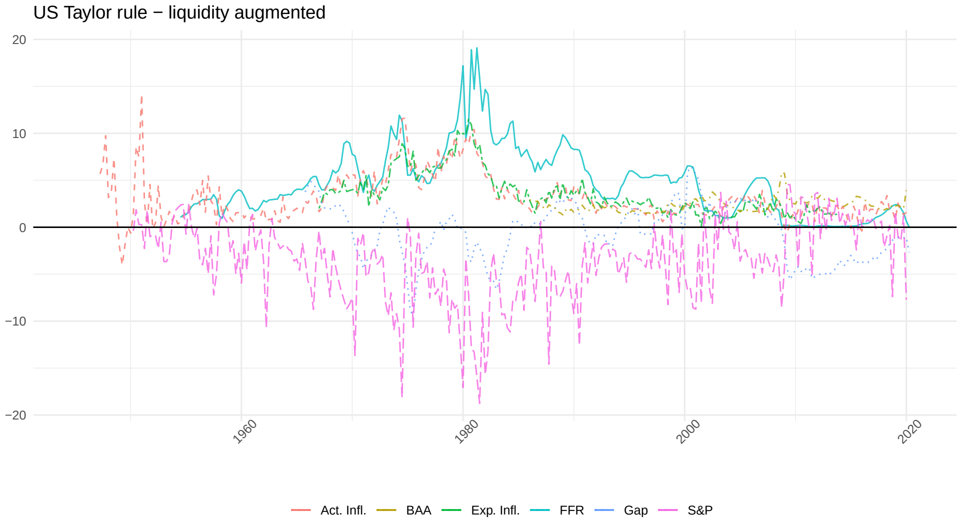

Figure 2: *Main variables analysed with financial liquidity measures, BAA and S&P500 spreads (dot-dashed and long-dashed)*

icy) to one of determinacy (aggressive policy)[8]. We revise the most common methods to estimate a Taylor rule, with the inclusion of financial liquidity proxies, before proposing a Markov Switching model to account for multiple regimes. Closer to our take to endogenise policy changes is Murray et al. [2015], where Hamilton [1989] algorithm for Markov processes estimation is applied to monetary policy rules. They explore the two-state case, finding two periods of undetermined policy.

The point estimates from Clarida et al. [2000] and Murray et al. [2015] are summarised in the tables below; in both tables μ represents the long-term inflation target, γ captures the (over) reaction to expected inflation as in $(1+\gamma)\, E_t \pi_{t+1}$, ω represents the reaction to output gap fluctuations, and finally ρ estimates the smoothing factor for the Federal Fund rate.

Motivated by these results, we first study the stability of the parameters of the Taylor rule in the post-WWII period. We propose a set of estimates of the decision rule followed by the monetary authority. After analysing the

[8]One of the first attempts to verify such break in policy is Clarida et al. [2000], who exogenously divide their sample in two periods. The Fed was passive during the first part of the sample, whereas it reacted aggressively after Volcker chairmanship. Boivin [2006] estimates a Taylor rule with drifting parameters over the full sample of real-time data. Inflation response was weak in the second half of the 1970s, but strong in the rest of the sample. The response to real activity decreased significantly after the 1970s. In the same vein, Primiceri [2005] employs a Bayesian SVAR to show that the Fed complied to the Taylor Principle even prior to Volcker.

Table 1: Clarida et al. [2000]

Exogenous break	μ	γ	ω	ρ
$Pre - Volcker$	4.24	-.17	.27	.68
	(1.09)	*(.07)*	*(.08)*	*(.05)*
$Post - Volcker$	3.58	1.15	.93	.79
	(.5)	*(.4)*	*(.42)*	*(.04)*

Table 2: Murray et al. [2015]

Markov State	μ	γ	ω	ρ
S_1	9.44	-.3	.46	.49
	(3.07)	*(.34)*	*(.26)*	*(.15)*
S_2	.59	.85	.58	.8
	(.66)	*(.23)*	*(.09)*	*(.05)*

full sample with OLS estimators[9], we exogenously split the sample in three sub-samples and compare the parameters. Then, we investigate possible structural breaks over the full sample via stability diagnosis. Third, we let the sub-sampling be endogenous with a Markov Switching estimation for two possible states. Throughout these steps, we also include liquidity condition in the monetary policy rule, to ascertain whether it enters the Fed's input set.

3.1 Specifications

We first assess the robustness of the traditional specification in comparison to the alternatives with liquidity proxies. Our interest lies particularly in the parameters stability over different methods, sample cuts, and when we include financial conditions in the information set[10]. This analysis solely focus on the interest-setting rule, while leaving aside direct management of liquidity in the economy. Optimal central bank balance sheet policy is nevertheless of paramount relevance and deserves further research effort.

Throughout this Section, we will estimate equation (1): r is the effective federal fund rate, π_{t+h} is h-period ahead expected inflation (mapped to forecasts, up to 8-quarter), $\hat{y}$ is output gap in percentage deviation, and $\boldsymbol{X}$

[9] Carvalho et al. [2018] provide motivation for using OLS in estimating monetary policy rules and quantify the bias of such method compared to GMM or IV.

[10] We also employ the Generalised Method of Moments over the same specifications as a way to circumvent endogeneity issues: these results are presented in the Appendix (B.3).

collects any additional variables used in the study, as detailed in Section (2).

$$r_t = (1-\rho)\left[\mu + (1+\gamma)\,E_t\pi_{t+h} + \omega\hat{y}_t + \boldsymbol{X_t'\beta}\right] + \rho r_{t-1} + \varepsilon_t \tag{1}$$

In equation (1), we assume that the Central Bank smooths its policy decision putting a weight $0 < \rho < 1$ on past interest rate level. Therefore, we need to recover estimates and confidence intervals from the estimated ρ. Moreover, we allow for inflation targeting including an intercept μ. ε_t captures the exogenous shock the monetary authority impulses to the rate path.

We focus our attention on a subset of parameters, β_i and γ. The sign and the magnitude of the former will tell how relevant other factors are for the Central Bank; on the other hand, γ will shed light on the robustness of the Taylor Principle. Established consensus points to a value close to $\gamma = .8$ following the onset of the Great Moderation and the inflation conquest carried out by Volcker.

Before exposing the results, we precise the specifications we estimate throughout this Section and briefly motivate their utilisation. Other specifications, although conceptually appealing, do not necessarily add interesting insights or fall outside the scope of investigating the role of financial liquidity.

Spec. I $r_t = (1-\rho)\left[\mu + (1+\gamma)\,E_t\pi_{t+1} + \omega\hat{y}_t\right] + \rho r_{t-1} + \varepsilon_t$: the standard specification as in Taylor [1993] and many other works. We employ one period ahead forecasts of GDP deflator as expected inflation and real-time gap for output slack. Considerably, we employ uniquely real time data so to track as closely as possible the information set available to the Central Bank.

Spec. II $r_t = (1-\rho)\left[\mu + (1+\gamma)\,E_t\pi_{t+1} + \omega\hat{y}_t + \beta\text{BAA}_t\right] + \rho r_{t-1} + \varepsilon_t$: we introduce in this specification a proxy for financial liquidity distress, namely the spread between BAA corporate bonds and 10 years Treasury bonds. This specification captures long term liquidity in the economy and thus accounts for the Fed's concern of longer run financial stability.

Spec. III $r_t = (1-\rho)\left[\mu + (1+\gamma)\,E_t\pi_{t+1} + \omega\hat{y}_t + \beta\text{S\&P500}_t\right] + \rho r_{t-1} + \varepsilon_t$: we test a second proxy for liquidity with this specification. We exploit quarterly returns on the stock market to obtain a spread with 3-month Treasury Bills. This spread captures shorter term concerns in financial liquidity, such as those that triggered the GFC. This specification is prone to picking up also solvability concerns.

3.2 Full sample analysis

The first step is to estimate our specifications on the full sample, overlooking the possibility of structural breaks or fluctuations in the parameters. The period covered varies with the series included in the specification, from a maximal of about 185 observations to a minimum of slightly less than 115[11]. Assuming parameter instability of any form and correct specification, this approach produces simple averages over the possible parameter values. In this sense, regimes that are more frequently in place will be more represented in the final estimate. Table (3) summarises the results of OLS estimates on the full length sample for the different specifications.

Table 3: OLS estimates in the full sample, up to 2013 Q2

$Var.$	Specification		
	I	II	III
μ	.1327	8.1884^{***}	.3355
	(.7766)	*(1.6854)*	*(.5268)*
$E_t\,(\text{GDP defl.})_{t+1}$	1.5811^{***}	$.9522^{*}$	$.9528^{***}$
	(.2736)	*(.4673)*	*(.1883)*
Real time $\hat{y}$	$.48^{**}$	$.2496^{+}$	$.2361^{*}$
	(.1439)	*(.1437)*	*(.0998)*
$BAAspr.$		-2.9673^{***}	
		(.4939)	
$SPspr.$			$-.4349^{***}$
			(.0951)
FFR_{t-1}	$.7782^{***}$	$.8643^{***}$	$.6877^{***}$
	(.0369)	*(.0289)*	*(.0402)*
Obs.	188	112	188
R^2	.8949	.9733	.9052
BIC	628	157	612

*Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '+' 0.1; SE in parentheses.*

These results are interesting in a number of aspects. First, the sample encompasses a variety of regimes: from the pre-Volcker era to the ZLB period, with the Great Moderation dwarfing other regimes in terms of observations. Therefore, it blends together different rules and behaviours with diverse weights.

[11] Greenbook real time data, in particular, are released to the public with a 5-year lag with respect to the estimates or forecasts and thus presents data until 2013. Moreover, data on BAA spreads are available only from 1986Q1.

Second, the addition of liquidity in the policy rule of the Central Bank marks a consistent violation of the Taylor Principle, with γ estimates below 1 for Specifications II and III. The inclusion of liquidity proxies significantly lowers the weight on inflation expectations. This finding is even more surprising when considering that the BAA spread series starts in 1986Q1, at the end of Volcker's mandate. These results suggest that financial conditions enter the decision set of the Central Bank with the expected sign. While the point estimates signal violations of the Taylor principle, standard errors are in the neighbourhood of 1: nevertheless, our results for Spec. II and III are in sharp contrast with traditional results, as those listed in Tab.(1) and (2). This first evidence begs for further and more refined inquiry into the role of financial liquidity in the Fed's decision set.

As mentioned before, the length of the sample blends multiple regimes and stances. In this light it is not surprising to find substantial parameters instability, as Table (3) presents. Under the hypothesis of μ as inflation target, its estimates greatly vary according to the sample and the specification. The same, with less variability, applies for ω and ρ, the output gap weight and the smoothing factor, respectively. To address this instability issue, we split the sample in three sub-samples, upon which we mold the assumption of different regimes[12].

3.3 Exogenous breaks

The estimates above might result from a variety of underlying regimes, smooth [Primiceri, 2005; Boivin, 2006] or discrete [Murray et al., 2015]. To account for such regime change, a straightforward approach is to look for relevant historical events that mark a discontinuity and estimate the policy rule before and after such dates. It boils down to splitting the sample in three sub-samples: post-WWII period, the Great Moderation, and the GFC. The latter in particular encompasses the liquidity injections of the Quantitative Easing in correspondence of the Zero Lower Bound period. This last condition distinguishes the first from the third sub-sample. In fact, in the postwar period the federal fund rate averaged around 5%, with a minimum value of .93% for one quarter only. The downside is that at date this sub-sample presents a small number of observations, which makes inference rather hard. We split the sample to obtain three phases:

(i) pre-Volcker regime [-:1981Q4],

[12] Appendix (B.2) offers the residuals plot for the full sample regression. Eye-balling these plots provides sufficient motives to carry out additional analyses on model instability.

(ii) the Great Moderation [1982Q1:2007Q2],

(iii) and finally the GFC [2007Q3:-].

Historically, the period covered by sub-sample (i) reports high inflation and federal fund rate, as well as volatile cyclical fluctuations. According to Clarida et al. [2000], among others, the Fed carried out an accommodative monetary policy in that period, following inflation instead of aggressively responding to its expectations. Hence, we expect to see values close to those presented in Table (1). Unfortunately, data availability severely limits the estimation of Spec. II.

The second chunk of data covers the inflation conquest and the steady, sustained growth that followed, with mild recessions and inflation in check. Supposedly, this conditions were brought about by a Central Bank eventually fighting back inflation aggressively, adjusting the FFR more than one-to-one with respect to expected inflation.

The third period starts right before the GFC. Data are still scarce: to date, we have about 10 years of quarterly data with hardly enough variation, mainly because of the FFR hitting the zero lower bound and hovering in its neighbourhood. Therefore, the estimates here shall be considered *cum grano salis*: statistical significance is hardly found with so little observations, but point estimate might be qualitatively informative.

Table 4: Exogenous splits, three samples

Sample	Spec.	μ	E_t (GDP defl.)$_{t+1}$	Real time $\hat{y}$	BAA spr.	SP spr.	FFR_{t-1}	Obs.	R^2	BIC
(i)	*I*	$-.2145$	1.4885^{***}	$.5266^{*}$			$.5985^{***}$	60	.7664	258
		(1.6457)	*(.362)*	*(.2207)*			*(.0882)*			
	II	.1106	$.8069^{***}$	$.2226^{+}$		$-.4938^{***}$	$.4022^{***}$	60	.8234	244
		(.9632)	*(.216)*	*(.1324)*		*(.1131)*	*(.0889)*			
(ii)	*I*	$-.7987$	2.1619^{**}	$.3646^{+}$			$.8495^{***}$	102	.9352	238
		(1.4227)	*(.6898)*	*(.2179)*			*(.0404)*			
	II	9.79^{***}	1.1145^{*}	$.6558^{**}$	-4.215^{***}		$.8642^{***}$	86	.9606	120
		(2.18)	*(.5147)*	*(.2027)*	*(.7594)*		*(.0299)*			
	III	$-.2352$	1.4082^{**}	.1749		$-.3954^{**}$	$.7892^{***}$	102	.9413	232
		(.9721)	*(.4705)*	*(.1503)*		*(.1188)*	*(.0425)*			
(iii)	*I*	-48.64^{+}	3.6837	-8.984^{+}			$.9846^{***}$	26	.9351	29
		(26.01)	*(8.22)*	*(4.37)*			*(.1015)*			
	II	2.7847	.1705	.0925	-1.1005^{*}		$.8004^{***}$	26	.945	27
		(.347)	*(.5859)*	*(.4117)*	*(.4948)*		*(.1249)*			
	III	-10.43	1.058	-1.662		.7416	$.9526^{***}$	26	.9375	30
		(9.185)	*(2.621)*	*(1.675)*		*(.549)*	*(.1024)*			

*Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '+' 0.1; SE in parentheses. (i) runs from the earliest available observation to 1981Q4; (ii) runs from 1981Q4 to 2007Q2; (iii) goes from 2007Q3 to the latest observation available, currently 2013Q2, as some data are published with a five years lag.*

Skimming through Table (4) it is interesting to compare the regimes in place. Although the heterogeneity restricts significantly the econometric robustness of such exercise, a number of regularities emerges.

In particular, γ estimates are highly volatile, both across and within subsamples. Contrary to the consensus (but in line with Boivin [2006]; Primiceri [2005]), the Fed broadly complied with the Taylor Principle, although Spec. II and III present values statistically close to 0 for γ. In the second period, in line with the narrative of a committed and credible Central Bank, γ is consistent with the Taylor Principle in all specifications, but present a significant volatility in the estimates. Strikingly, inflation expectations seem to disappear from the relevant set for monetary policy-making, as its estimates are generally not significant.

Likewise, output gap measures seem less relevant in the wake of the GFC than in previous periods, when ω estimates take expected values and signs without much volatility. Implicit inflation target, μ, displays an erratic behaviour and provide a less than convincing picture over the periods.

Focusing on cross samples comparison, the BAA spread holds robust estimates over time and across specifications, like the S&P500 spread, pointing to our intuition that financial conditions are key. When liquidity dries up because of financial or real turmoil (and hence spreads increase) the monetary authority puts in place accommodating policies by decreasing the reference interest rate. On top of that, there is a noticeable increase in the federal fund rate persistence over time. The first sub-sample present a quite volatile policy rate, whilst sub-sample (ii) reports significant increases in ρ. The most recent sub-sample (iii), with severely scarce observations, includes a key policy rate that barely moves, with other variables displaying more variability. This explains why in all regression the most significant variable is the lagged interest rate, while all other variables present odd estimates. Nevertheless, some results are suggestive of fundamental parameters instability, consistently with the Fed switching to QE policies (*de facto* liquidity injections).

These early results point towards an inconsistent behaviour of the Central Bank – if we assume its only decision function takes the form of a strictly parametrised Taylor rule. In particular the great deal of volatility in the estimates across sub samples motivates a deeper investigation in the stability of the parameters. This instability mirrors a changing policy stance for the monetary authority, as encapsulated by the Taylor rule specifications. The next step, therefore, is to diagnose possible sources of structural breaks or parameter variability and to address this with proper, flexible tools.

4 DIAGNOSTICS ON STRUCTURAL BREAKS AND MARKOV SWITCHING

Sub-sampling according to historical events is an appealing device, but it does not provide a robust statistical motivation. To address this shortcoming, we exploit a number of tests that diagnose the stability of the estimated parameters. Compared to exogenous sub-sampling, this approach is more data driven, as it makes use of the information contained in the sample to check for breaks and eventually propose the most likely break date(s). We run these diagnostics on the full sample to identify precise dates. In line with the established consensus, we expect to find breaks in correspondence of the Volcker chairmanship and the GFC.

We take the models estimated on the full sample and run first a simple CUSUM diagnostic test, then a Chow [1960] test. The latter in particular is flexible enough to provide an optimal segmentation of the sample based on parameters stability. Based on the Bayes Information Criterion, the Chow test can produce the most likely date of break, provided that we require only one single date; or it can provide the most likely number of breaks in the sample. We exploit these properties in our analysis.

As straightforward check, CUSUM tests do not report significant fluctuations in the empirical process, meaning that the cumulative sum of the residuals eventually levels off to 0 without significant erratic deviations. It is nevertheless interesting to remark how persistent over time the deviations are and how consistently the CUSUM statistics builds up towards the end of the sample. Plots of this diagnostic are presented in the Appendix (B.4). The F-Test derived from Chow [1960] points in another direction, though. The output of the test actually reports multiple breaks along the sample, some of which occur with unexpected timing.

When only the most likely date break is requested, two out of three specifications report it around two years into Volcker's Chairmanship (specifications I and III, involving BAA spread, which start in 1986), decidedly in line with the established consensus. What is more interesting is the picture depicted by Fig.(3): these specifications, especially those including the 3-month spread variable, report F-statistics hovering above the threshold for well more than one observation. The results of optimal segmentation of the sample pave the way to the Markov switching estimation below as it motivates further inquiry into the existence of multiple policy regimes.

Table (5) summarises the analysis on optimal segmentation. It highlights, also, that most of the specifications likely involve more than one structural break. On top of Volcker's regime change, one would reasonably expect that

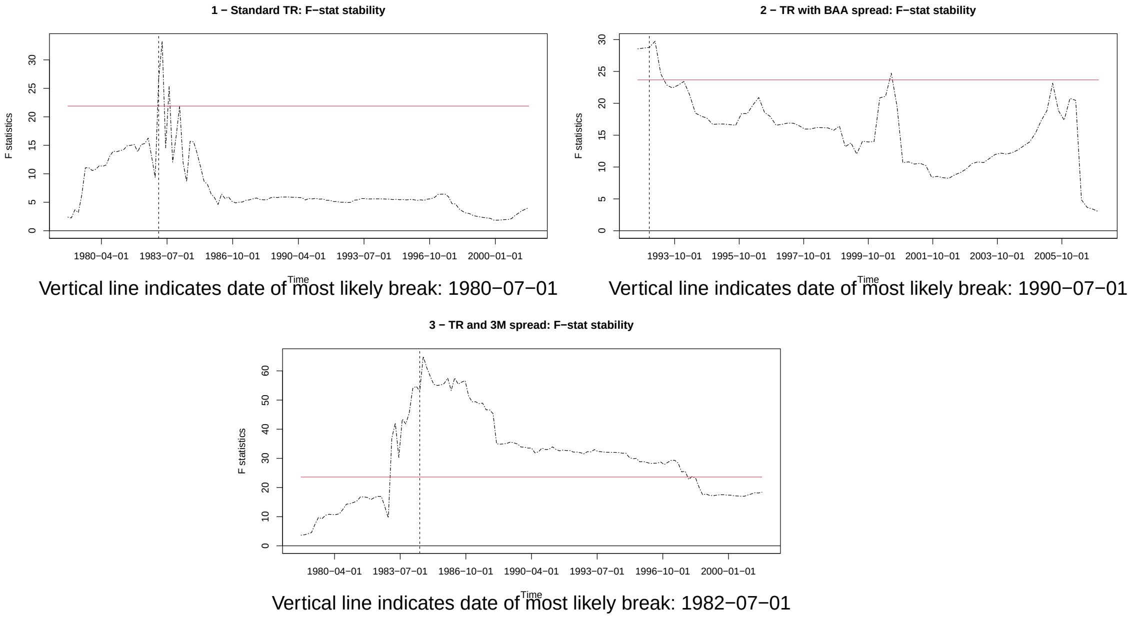

Figure 3: *F-statistic plots for specifications I to VIII. Dashed line indicates the statistics value, solid horizontal line marks the significance area at 95%. Individual captions offers most likely date for a singular structural break in the specification pointed by the vertical dashed line.*

Table 5: Optimal segmentation and break dates

	Specification		
	I	II	III
Sing. break	1980Q3	1990Q3	1982Q3
N. of breaks	2	3	2
Date 1	1980Q3	1989Q4	1980Q3
Date 2	1987Q3	2000Q4	1987Q3
Date 3	-	2008Q3	-

The first row presents the most likely break admitting only a single one. Third to fifth rows present break dates when up to 5 breaks are allowed.

the mix of ZLB and unconventional policies would be sufficient to mark an additional break. Moreover, a striking result is that in two cases (specifications I and III) the end of Volcker's two terms is also a candidate point for a structural discontinuity[13].

These results suggest that there has been a structural break when Volcker left the Chair, with Greenspan chairmanship introducing an additional new regime. Hence, there might be one or more than one discrete regimes of monetary policy, among which the Federal Reserve switches back and forth. Therefore, it is clearly worth pursuing additional insights into these structural breaks with adequate techniques.

4.1 Markov Switching estimation

We further unconstrain the data via a Markov Switching model: we adopt Murray et al. [2015]; Hamilton [1989, 1994] approach to our extended sample and only assume it comprises k discrete states. We restrict our analysis to $k = 2$, in line with the discussion on the determinacy or indeterminacy regimes at the beginning and at the end of our sample. As aforementioned, pre-Volcker and post-GFC periods yield deeper insight on the functioning of the Federal Reserve monetary policy conduct away from the Great Moderation "steady state." Therefore, eq.(1) takes now the form

$$\begin{aligned} r_t = \left(1-\rho^S\right)\left[\mu^S + \left(1+\gamma^S\right)E_t\pi_{t+h} + \omega^S\hat{y}_t + \boldsymbol{X_t'\beta^S}\right] + \rho^S r_{t-1} + \varepsilon_t^S \\ var\left(\varepsilon_t^S\right) = \sigma^S \qquad \text{with} \quad S = k \in \{1,\dots,K\} \end{aligned} \tag{2}$$

Hamilton [1989] provides the algorithm to estimate our specifications with k states, generating also transition matrices and smoothed probabilities to pick the prevailing regime in any date t. For every specification, we allow for the variation of every parameter and the variance: in k different states, all parameters are freely estimated, with no constraint posed by other states' estimates[14].

Table (6) presents estimates for the two state Markov switching model. In contrast to the results of Murray et al. [2015], Specification I – mirroring

[13] Volcker was nominated July 25^{th}, 1979, sworn shortly after August 6^{th}, and left the Chair in August 11^{th}, 1987. In our quarterly data set it translates in 1979Q3:1987Q3. This last insight deserve more documentary research effort, since it could signal that it was actually Greenspan to introduce a Taylor-type reaction function in the Fed decision process.

[14] Alternatively, a subset of parameters can be optionally estimated across all regimes, so its estimate is invariant to the prevailing regime.

Table 6: Estimates for $k = 2$ Markov Switching model

Spec.	State	μ	$E_t(\text{GDP defl.})_{t+1}$	Real time $\hat{y}$	BAA spr.	SP spr.	FFR_{t-1}	$Adj.R^2$	BIC
I	S_1	$-.7759$	1.693^{***}	.3554			$.6128^{***}$	.7853	518
		(2.025)	*(.4816)*	*(.329)*			*(.1118)*		
	S_2	$-.4052$	2.012^{***}	$.6329^{**}$			$.9208^{***}$	.9758	
		(1.199)	*(.4131)*	*(.2274)*			*(.0253)*		
II	S_1	2.74^{*}	$-.7505^{+}$	.0564	$-.3956$		1.099^{***}	.9987	142
		(-)	*(-)*	*(-)*	*(-)*		*(.0234)*		
	S_2	11.01^{***}	.3199	$.442^{**}$	-4.066^{***}		$.8385^{***}$	.9765	
		(1.264)	*(.3338)*	*(.1367)*	*(.3692)*		*(.0234)*		
III	S_1	1.45	$.5299^{***}$	$-.2855^{+}$		$-.6061^{***}$	$-.0642$	.8505	518
		(1.322)	*(.1596)*	*(.1458)*		*(.0938)*	*(.1416)*		
	S_2	$-.8855$	1.561^{***}	$.4535^{*}$		$-.2201$	$.8982^{***}$	.9623	
		(.9915)	*(.3917)*	*(.2005)*		*(.1712)*	*(.0286)*		

*Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '+' 0.1; SE in parentheses.* (−) *stands for non-convertible SE: significance is hence derived from the main regression.*

those of the cited work – finds two states complying to the Taylor Principle[15]. This traditional Taylor rule presents two distinct states that differ in terms of reaction *intensity.* S_2 estimates present larger coefficients in absolute values for virtually all variables. Focusing on γ estimates, both states comply to the Taylor principle, pointing towards a *more aggressive* reaction in the second state. This evidence does not align with the established consensus, but rather corroborate Orphanides [2004, 2001] findings.

Interestingly, S_1 is more likely to be in place during downturns, with a lower persistence of the policy rate. This last piece of evidence suggests that the Fed might react asymmetrically to evolving economic conditions: rapidly in light of downturns, cautiously when the recovery materialises. With respect to the timing, it appear to precede economic turmoil periods: it covers roughly the years of the oil shock, the high inflation that followed, the dot-com crash, and the early stages of the GFC. It is suggestive to connect this regime with a cautious approach of the Federal Reserve: as soon as slowdown factors build up, the policy intervention intensity needs to adjust accordingly. By contrast, when risk, uncertainty, and sources of slowdown are a weak threat, the Central Bank acts with decision to steer the economy.

Turning to the financial specifications (II and III), the picture is less clear but insightful. Estimates for γ display both regimes of determinacy and indeterminacy. Across these two specifications estimates for the weight of the spread are rather consistent with previous results: to a higher relevance of the financial condition corresponds a lower reaction to expected inflation and

[15]Most likely this discrepancy arises from our longer sample and slightly different method employed in the estimation.

real activity (summarised in S_1 for both Specifications), putting in place an accommodative policy regime. Again, the interest rate persistence is lower in the undetermined regime. The prevailing period for the accommodative monetary policy corresponds roughly to Volcker's first term and the first half of the 1970s: this evidence is at odds with the established narrative that sees Volcker putting swiftly in place an aggressive regime to tame inflation. Looking at the time dimension of these regimes, the picture is complementary to the one drawn from the traditional Taylor rule. In both cases, the indeterminate regime is in place at times of economic and financial distress. One difference is worth noticing: in Specification III the ZLB period is described by an active monetary policy regime, while the opposite is found for Spec. II. This difference depends on the fact that bonds are more exposed to the liquidity risk, as well as incorporate a quantity of default risk. This latter factor is less present in the most capitalised companies on the financial market[16] and might drive the result.

The panels collected in Fig. (4) depict the prevailing state along the sample for the estimates of Table (6). We also propose the transition matrices for the two estimated states. In general, every state appear to be an attractor: virtually all states will persist to the following period with a probability greater than .8.

Table 7: Transition matrices

Spec.I	S_1	S_2
S_1	.945	.171
S_2	.055	.829
Spec.II	S_1	S_2
S_1	.9086	.2399
S_2	.0914	.7601
Spec.III	S_1	S_2
S_1	.8451	.0511
S_2	.1549	.9489

Transition probabilities for two states Markov process. Columns are current state, hence conditional on it next state is one of the rows.

This collection of evidences points towards a fundamental instability in parameters of the Taylor rule, entailing periods of violation of the TP and a consistent role of financial liquidity. We retrieved periods with – theoretically – destabilising monetary rules and inflation under control at the same time,

[16] While it is true that during the GFC some systemic banks underwent actual bailouts, it is disputable for the rest of the companies listed in the S&P 500.

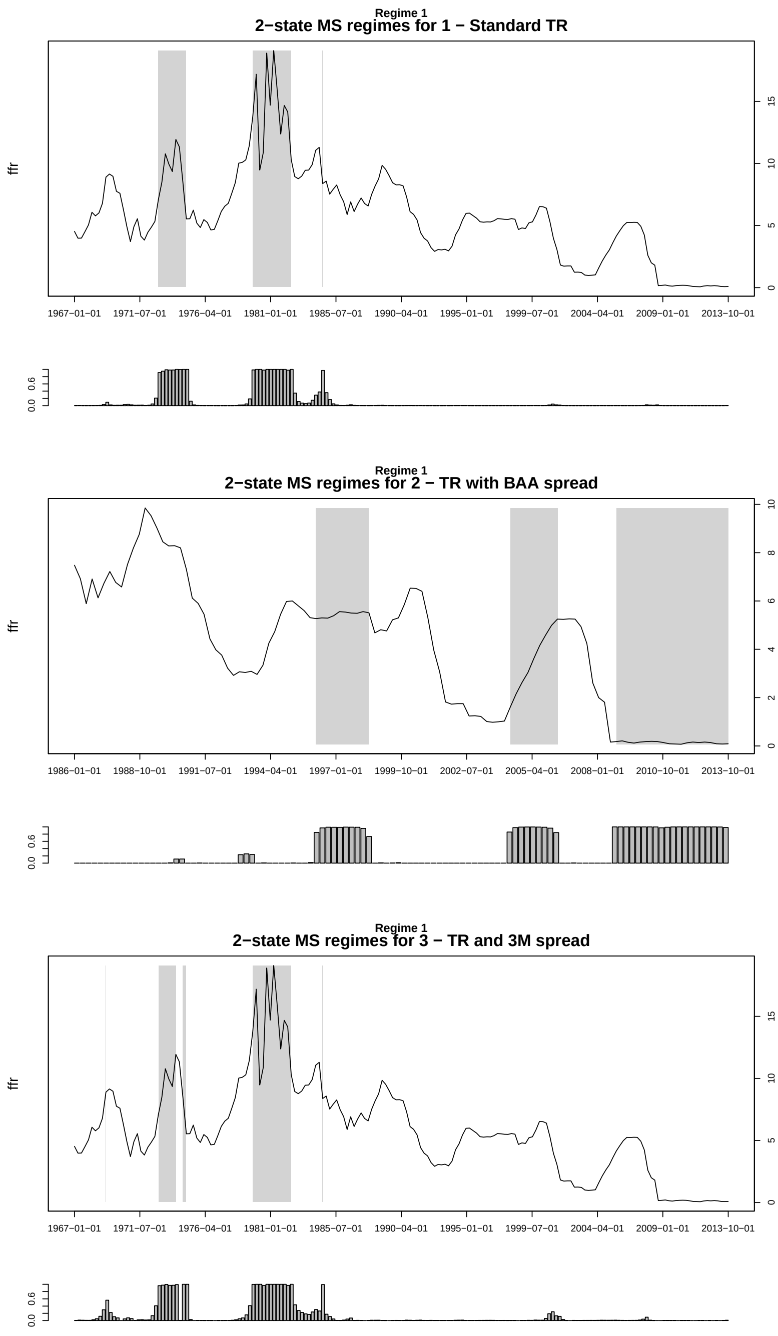

Figure 4: *Markov States: above shaded areas correspond to S_1 prevailing over S_2, below smoothed probabilities for S_1.*

once liquidity is included in the decision set of the monetary authority. These results suggests that the Taylor Principle might not play a fundamental role in anchoring the inflation expectations: agents could – and did, according to our findings – form expectations about the future paths of prices that are non-degenerate even when the Central Bank deviates from the prescriptions of the New Keynesian workhorse. Other factors are therefore at play in anchoring inflation expectations: while the influence of Central Bank actions remains relevant for the determination of the inflation behaviour, the Taylor Principle appear to be less than granitic.

In our proposed specifications for the monetary rules, proxies for liquidity and for financial conditions have a sizeable and robust role across different methodologies. As soon as liquidity dries up, financial conditions worsen, the Federal Reserve Bank acts and reacts lowering the reference rate. This finding is consequential since these violations of the Taylor Principle are not accompanied by degenerate behaviour of inflation, at least in the most recent cases.

5 CONCLUSION

In this paper, we collect and aggregate an important number of data on the US economy, both real time and revised series. Moreover, we also provide a flexible and easy-to-tune database including granular information on expectations and now-/forecasts, from policy-makers and economic agents. We use this extensive database to empirically investigate the stability of the monetary policy rule in the US postwar period and to test whether the Federal Reserve Bank considers financial markets liquidity in its policy decisions.

We study the robustness of the standard Taylor rule embodied in NKDSGE models and embedded within several Central Banks' decision set. A standard rule reveals compliance – with varying intensity – of the Fed to the Taylor principle over the whole period considered, contrary to the established consensus that identifies the working of the TP in the post-Volcker regime. Furthermore, the inclusion of liquidity spreads reveals that the Fed also takes into account financial conditions in its interest rate setting. This inclusion produces violations of the Taylor Principle. We also provide statistical evidence for the presence of structural breaks in the policy rule.

Estimating Markov Switching models, we find multiple monetary policy regimes. When considering financial markets liquidity, the Fed reacts less than one-to-one to expected inflation in periods of looming economic uncertainty and distress. In such cases, it also weights more the liquidity conditions in the economy. Conversely, in tranquil times it switches back to a standard Taylor rule. These results challenge the narrative of a passive US Central Bank until the regime switch associated to Volcker's chairmanship.

All in all, across estimates we find evidence of generalised parameters instability. The potential effects of such instability on the dynamics of inflation and of other macroeconomic aggregates are an important subject for future research. Our findings shed new light on the functioning of the US monetary authority and on its information set. While these results revolve around the interest-setting leg of the monetary policy, they pave the way to more research on the whole tool-kit of central banking. Ideally, a characterisation of the central bank decision mapping would include monetary aggregates and liquidity management alongside with an interest rate setting rule, so to describe the whole set of tools that a monetary authority can leverage to respond to economic fluctuations.

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A DATA SOURCES AND TRANSFORMATIONS

Table 8: Data details for the US

Variable	**Source**	**Mnemonics**	**type**	**transformation**	**link**
FFR	St. Louis Fed	FEDFUNDS	rate	aggregated to quarters	FRED API
Deflator	Phil Fed	gPGDP	rate	filtered to latest observation for each quarter	xlsx, doc
CPI	Phil Fed	gPCPI	rate	filtered to latest observation for each quarter	xlsx, doc
Core	Phil Fed	gPCPIX	rate	filtered to latest observation for each quarter	xlsx, doc
Realtime y-gap	Phil Fed	ROUTPUT	bls of $	regressed to quadratic time trend, extrapolate last percentage difference	xlsx
Ex post y-gap	St. Louis Fed	GDPPOT & GDPC1	levels	percentage deviation wrt potential	FRED API
Unemployment	St. Louis Fed	UNRATE	rate	no	FRED API
Layoff rate	St. Louis Fed	ICSA & PAYEMS	levels	ratio and %	FRED API

Footnoted series start in 2007Q1.

In Tab.(10) r is the FFR, $E_t\pi^i$ is now- or one period ahead forecast for inflation measure i, $E_t\hat{y}_t$ is real time output gap, $\hat{y}_t$ is capacity utilisation, $\hat{u}_t$ is fluctuations around the natural unemployment rate, SP and BAA are the spreads.

Table 9: Data details for the US

Variable	Source	Mnemonics	type	transformation	link
Empl_fluct	St. Louis Fed	NROU, UNRATE	pct pts rate diff	natural $\bar{u}$ minus current u	FRED API
BBA spread	St. Louis Fed	BAA10Y	rate	no	FRED API - discontinued
S&P500 spread	Yahoo! fin	ˆGSPC	rate	difflog minus tbill rate	web
US deficit	St. Louis FED & BEA	M318501Q027NBEA & GDP	% of GDP	from monthly to quarterly and ratio to GDP	FRED API
debt to GDP	St. Louis FED	GFDEGDQ188S	ratio	no	FRED API
debt level	St. Louis FED	GFDEBTN	millions of $	no	FRED API
debt growth	ST. Louis FED	GFDEBTN	rate	diff log	FRED API
debt held by FED	St. Louis FED	FDHBFRBN	billions of $	no	FRED API
% debt by FED	St. Louis FED	FDHBFRBN / GFDEBTN	share	ratio	FRED API
SPF:CPI rate	Phil Fed	SPFCPI_i	incompl. panel	tidy	xlsx doc
SPF:CORECPI[17]rate	Phil Fed	SPFCORECPI_i	incompl. panel	tidy	xlsx
SPF:PCE rate[18]	Phil Fed	SPFPCE_i	incompl. panel	tidy	xlsx
SPF:COREPCE[19]	Phil Fed	SPFCOREPCE_i	incompl panel	tidy	xlsx
SPF:BBA spr	Phil Fed	/	incompl. panel	tidy	web
rev'd CPI	FRED	CPIAUCSL	rate	difflog*400	web
rev'd deflator	FRED	GDPDEF	rate	difflog*400	web
rev'd PCE less food & energy	FRED	PCEPILFE	rate	difflog*400	web
rev'd CPI less food & energy	FRED	CPILFESL	rate	difflog*400	web

Footnoted series start in 2007Q1.

Table 10: Correlations

	r_t	r_{t-1}	$E_t\pi_t^{defl}$	$E_t\pi_{t+1}^{defl}$	$E_t\pi_t^{cpi}$	$E_t\pi_{t+1}^{cpi}$	$E_t\pi_t^{pce}$	$E_t\pi_{t+1}^{pce}$
r_t	1	0.982	0.547	0.693	0.393	0.518	0.729	0.822
r_{t-1}	0.982	1	0.549	0.682	0.356	0.484	0.735	0.817
$E_t\pi_t^{defl}$	0.547	0.549	1	0.543	0.476	0.206	0.667	0.629
$E_t\pi_{t+1}^{defl}$	0.693	0.682	0.543	1	0.410	0.571	0.727	0.813
$E_t\pi_t^{cpi}$	0.393	0.356	0.476	0.410	1	0.493	0.500	0.431
$E_t\pi_{t+1}^{cpi}$	0.518	0.484	0.206	0.571	0.493	1	0.469	0.582
$E_t\pi_t^{pce}$	0.729	0.735	0.667	0.727	0.500	0.469	1	0.861
$E_t\pi_{t+1}^{pce}$	0.822	0.817	0.629	0.813	0.431	0.582	0.861	1
$E_t\hat{y}_t$	0.616	0.612	0.304	0.218	0.223	0.214	0.295	0.357
$\hat{y}_t$	0.614	0.575	0.145	0.192	0.223	0.204	0.153	0.222
$\hat{u}_t$	−0.735	−0.723	−0.311	−0.347	−0.260	−0.314	−0.366	−0.449
SP	−0.622	−0.629	−0.499	−0.406	−0.179	−0.292	−0.466	−0.533
BAA	−0.623	−0.552	−0.311	−0.431	−0.471	−0.414	−0.399	−0.461

	$E_t\hat{y}_t$	$\hat{y}_t$	$\hat{u}_t$	SP	BAA
r_t	0.616	0.614	−0.735	−0.622	−0.623
r_{t-1}	0.612	0.575	−0.723	−0.629	−0.552
$E_t\pi_t^{defl}$	0.304	0.145	−0.311	−0.499	−0.311
$E_t\pi_{t+1}^{defl}$	0.218	0.192	−0.347	−0.406	−0.431
$E_t\pi_t^{cpi}$	0.223	0.223	−0.260	−0.179	−0.471
$E_t\pi_{t+1}^{cpi}$	0.214	0.204	−0.314	−0.292	−0.414
$E_t\pi_t^{pce}$	0.295	0.153	−0.366	−0.466	−0.399
$E_t\pi_{t+1}^{pce}$	0.357	0.222	−0.449	−0.533	−0.461
$E_t\hat{y}_t$	1	0.736	−0.881	−0.551	−0.355
$\hat{y}_t$	0.736	1	−0.889	−0.393	−0.557
$\hat{u}_t$	−0.881	−0.889	1	0.543	0.533
SP	−0.551	−0.393	0.543	1	0.235
BAA	−0.355	−0.557	0.533	0.235	1

B EMPIRICAL APPENDIX

B.1 Output gap

We detail the econometric derivation of the real time output gap from the Greenbook data set. This data set offers data and forecasts prepared by the Federal Reserve System staff for the Federal Open Market Committee meetings, where policy rate decisions are discussed. To gauge the output gap at any date t, we select all observations up to time t, run a simple quadratic time trend and keep the last observation residual. This term is then normalised as percentage deviation from the computed trend and used as output gap observation. The algorithm is the following:

1 set a number j of observations sufficiently high to compute precise estimates

2 for all t in $[j, T]$ run the following routine

   i sub-select observations in the $[j, t]$ interval

   ii estimate $y_s = \alpha_1 s + \alpha_2 s^2 + \epsilon_s,\ s = j, j+1, \ldots, t$; recover fitted values $\hat{y}_s$

   iii compute $gap_t = \left(\frac{y_t - \hat{y}_t}{y_t}\right) \times 100 = \frac{\hat{\epsilon}_t}{y_t} \times 100$; keep the latest observation/nowcast prior to the FOMC meeting

3 stack and date all gap_t to construct the *real time output gap* variable

B.2 Full sample regression: residuals

Fig.(5) plots the residuals generated from the regression on the full sample. As OLS sort of averages over the full sample, sudden and ample fluctuations in the residuals point to observations where the model underperforms. This occurs typically in the late '70s, late '80, and around the GFC period.

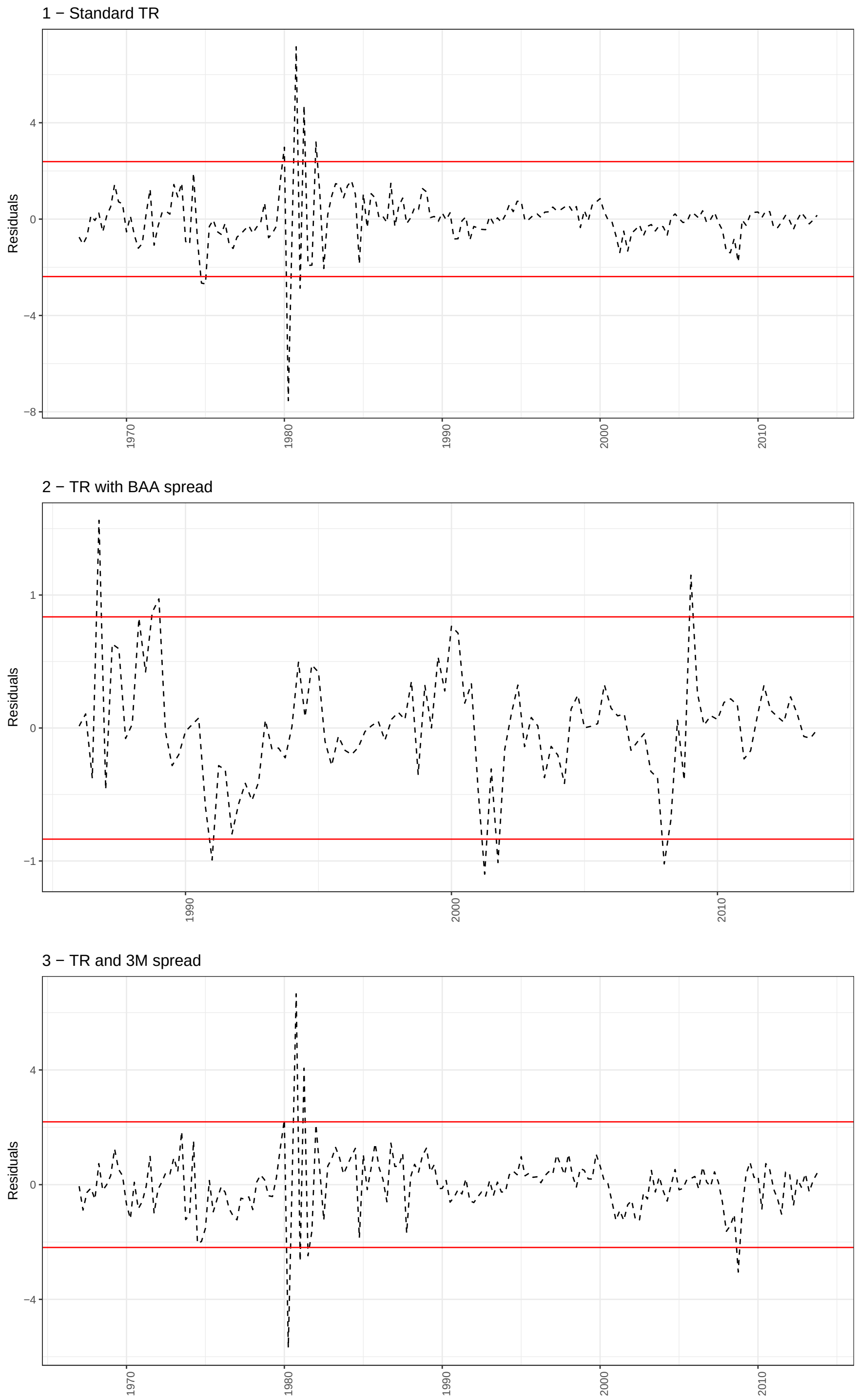

Figure 5: *Residuals plot for the three specifications. Dashed line depicts single residuals as time series, solid horizontal lines contour the 2-SDs area around zero, the expected – and empirical – residuals mean.*

B.3 GMM

Table 11: GMM estimates in the full sample, up to 2018 Q2

	Specification		
	I	*II*	*III*
μ	−.9766	12.24*	.5633
	(1.68)	*(4.944)*	*(.1.7384)*
$E_t\,(\text{GDP defl.})_{t+1}$	1.8765*	.6913	.8099
	(.8457)	*(.7656)*	*(.8209)*
$Realtime\hat{y}$	.8096*	.3479	.614*
	(.3305)	*(.2919)*	*(.2858)*
$BAAspr.$		−3.4725***	
		(.8153)	
$SPspr.$			−.4231
			(.3903)
FFR_{t-1}	.907***	.9022**	.8966***
	(.0332)	*(.0222)*	*(.0416)*
Obs.	188	112	188

*Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '+' 0.1; SE in parentheses.*

B.4 CUSUM test plots

This section presents the CUSUM plots for the three specifications of the Taylor rule studied in Section (3). The dashed line marks the cumulative sum of residuals, whilst the horizontal solid lines define the significance areas, in which the residuals sum signals a change in the underlying data generating process.

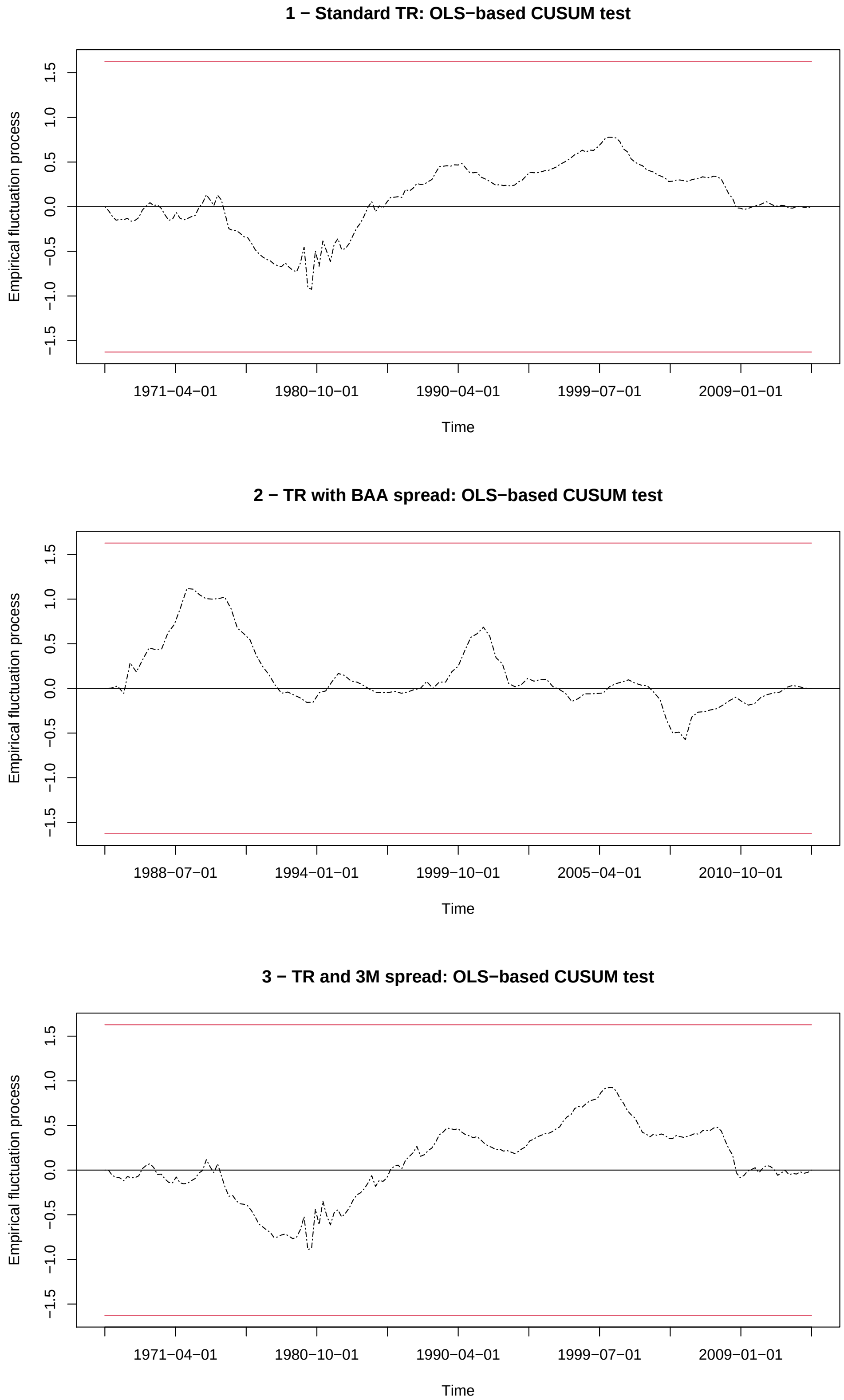

Figure 6: *Dashed line depicts cumulative sum of residuals, solid horizontal lines mark the significance area for changes in the underlying DGP.*