RISK MANAGEMENT, NONLINEARITY AND AGGRESSIVENESS IN MONETARY POLICY: THE CASE OF THE US FED

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1. The views expressed in this paper are those of the authors and do not necessarily reflect those of the University of Namur and the ECB.

1. Motivation

- Linear Taylor rules
- Non-linear Taylor rules:
  - Asymmetric loss function: inflation and the output gap
    - Martin and Milas, Taylor and Davradakis (2006), inflation zone targeting
    - Bec *et al.* (2002), Rabanal (2004), Cukierman and Muscatelli (2008)
  - Non-linear Phillips curve
- Another source of non-linearity: Uncertainty
- “Uncertainty is not just an important feature of the monetary policy landscape; it is the defining characteristic of that landscape” (Greenspan, 2003)

- Types of uncertainty:
  - Data uncertainty: data revisions and noisy variables (output gap)
    - Staiger *et al.* (1996), Wieland (1998), Rudebusch (2001), Estrella and Mishkin (1999), Smets (1999), Orphanides *et al.* (2000); Peersman and Smets (2001); Aoki (2003).
  - Parameter uncertainty: impact of policy and structure of the economy
    - Brainard (1967), Svensson (1999)
    - Estrella and Mishkin (1999), Peersman and Smets (1999), Rudebusch (2001)
    - Flamini and Milas (2011), Söderström (2002), Giannoni (2007)
  - Shock uncertainty: robust control
    - LQ framework + shock uncertainty = certainty equivalence
    - Giannoni (2002), Onatski and Stock (2002)

- US Fed Governors’ view:
  - “While the linear-quadratic framework may provide a reasonable approximation to how monetary policy should operate under fairly normal circumstances, this approach is less likely to be adequate for thinking about monetary policy when the risk of poor economic performance is unusually high” (Mishkin, 2008).
- Risk management approach to monetary policy:
  - “Given our inevitably incomplete knowledge. . . . a central bank needs to consider not only the most likely future path for the economy but also the distribution of possible outcomes about that path” (Greenspan, 2004)

- Risk management and non-linearity:
  - Mishkin (2008): “Policy in this setting tends to respond aggressively when a large shock becomes evident; for this reason, the degree of inertia in such cases may be markedly lower than in more routine circumstances”. “The Federal Reserve’s policy strategy is aimed at providing insurance to help avoid more severe macroeconomic outcomes”.
  - Bernanke and Reinhart (2004): “…policymakers are well advised to act preemptively and aggressively to avoid facing the complications raised by the zero lower bound”.

- Risk management considerations relevant because: "…the conduct of monetary policy in the United States has come to involve, at its core, crucial elements of risk management" Greenspan (2004).

2. What we do

- Estimate regime switching models, strength of the response of monetary policy to macroeconomic conditions depends on risk
- Don’t distinguish source of uncertainty
- Measures of risk:
  1. Dispersion of inflation forecasts
  2. Risk in financial markets

- Steps:

1. Linear Taylor rules
2. Specification of STR models
3. Test for neglected non-linearity
4. Estimate non-linear Taylor rules

3. Data

- Greenspan period: 1987Q4 – 2005Q4
- Dependent variable: quarterly average of daily effective Federal Funds Rate
- Inflation: four quarter rate of change in the implicit output deflator.
- Output gap: percent deviation of real GDP from potential output

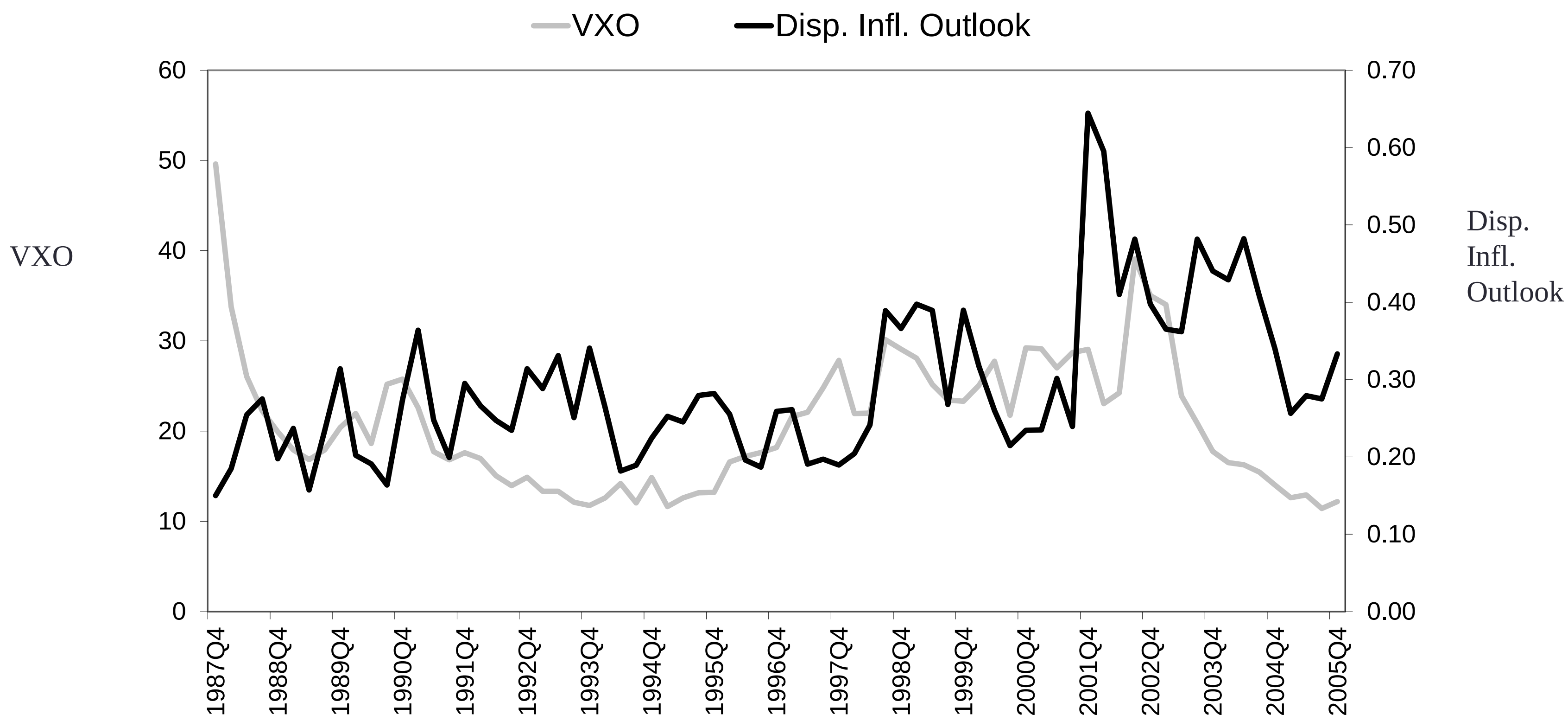
- Real time data from the Greenbook (Federal Reserve Bank of Philadelphia) - meeting closest to the middle of the quarter (Orphanides, 2001, 2003 and 2004)
- Risk measures:

1. Dispersion of inflation forecasts - Survey of Professional Forecasters (SPF), Philadelphia Fed

$$\sigma_{\pi t} = \frac{\pi^{75} - \pi^{25}}{\pi^{50}}$$

2. Risk in financial markets: VXO index - Chicago Board Options Exchange (CBOE)

Measures of macroeconomic risk



4. Linear monetary policy rules

Specification

$$r_t = (1-\rho_1-\rho_2)\left(\alpha + \beta\pi^e_{t|t+3} + \varphi x^e_{t,t} + \phi x_{t-1} + \theta(x^e_{t|t+3} - x_{t-1})\right) + \rho_1 r_{t-1} + \rho_2 r_{t-2} + \eta_t$$

- Clarida *et al.* (1998): $\rho_2 = \theta = \phi = 0$
- Clarida *et al.* (1999): $\theta = \phi = 0$
- Orphanides (2003): $\rho_2 = \varphi = 0$

Results

Variable	Clarida *et al.* (1999)		Clarida *et al.* (1998)		Orphanides (2003)	
	Estimate	**Std. Err.**	**Estimate**	**Std. Err.**	**Estimate**	**Std. Err.**
Constant	0.40	0.28	0.87	0.37**	-0.07	0.43
$\pi^e_{t\|t+3}$	1.92	0.12***	1.73	0.16***	2.16	0.19***
x_{t-1}					1.04	0.13***
$x^e_{t,t}$	0.74	0.05***	0.63	0.06***		
$x^e_{t\|t+3}$ - x_{t-1}					1.41	0.37***
r_{t-1}	0.63	0.04***	1.29	0.09***	0.74	0.04***
r_{t-2}			-0.52	0.08***		
Diagnostic tests						
Adjusted R-squared	0.98		0.99		0.98	
RMSE	0.32		0.26		0.31	
AIC	-2.20		-2.63		-2.26	
Autocorr. 1	37.31***		0.39		21.59***	
Autocorr. 4	9.91***		0.44		5.96***	

Notes: (1) $\pi^e_{t|t+3}$ = expected inflation between periods *t-1* and *t+3*, x_{t-1} = output gap for period *t-1*, $x^e_{t,t}$ = expected output gap for period *t* , $x^e_{t|t+3}$ = expected output gap for period *t+3*, r_{t-i} = the federal funds rate at time *t-i*, $i \in \{1,2\}$. The models are estimated by least-squares over the period 1987:4-2005:4. The standard errors are based on the Newey-West heteroskedasticity and serial correlation robust estimator. Autocorr. 1 and 4 denote the Breusch-Godfrey Serial Correlation LM Test for first and fourth order autocorrelation, F statistics. ***, ** and * denote statistical significance at the 1%, 5% and 10% level, respectively.

5. Non-linear Taylor rules

Specification - STR model

$$r_t = z_t^{'}\Psi_0 + z_t^{'}\Psi_1 G(\gamma, c, s_t) + \mu_t$$

Where:

$$z_t^{'} = [1 \ \pi^e_{t|t+3} \ \ x^e_{t|t} \ \ x_{t-1} \ (x^e_{t|t+3} - x_{t-1}) \ \ r_{t-1} \ \ r_{t-2}]$$

$$\Psi_i = [\alpha_i^* \ \ \beta_i^* \ \varphi_i^* \ \phi_i^* \ \ \theta_i^* \ \ \rho_{1,i} \ \ \rho_{2,i}]' \text{, } i = 0,1$$

Transition functions

- Logistic: $G(\gamma, c, s_t) = (1 + \exp(-\gamma(s_t - c)))^{-1}$
- Exponential: $G(\gamma, c, s_t) = 1 - \exp\left(-\gamma(s_t - c)^2\right)$

Where:

- S_t is the transition variable
- $\gamma > 0$ captures the speed of the transition across regimes
- c is the threshold for regime change

Transition functions (con't)

- Transition function bounded between 0 and 1:
- Regime 1: Ψ_0
- Regime 2: $\Psi_0 + \Psi_1$
- Smooth transition between the two regimes.

Testing for neglected nonlinearity

- Misspecification error in linear models?
- Non-linearity is an empirical question.
- Transition variables:
  1. Dispersion of inflation forecasts
  2. Risk in financial markets
  3. Inflation (Dolado *et al.*, 2005; Kim *et al*., 2005; Cukierman and Muscatelli, 2008)
  4. Output gap (Bec *et al.*, 2002; Rabanal, 2004)
  5. Fed Funds rate (Kesriyeli *et al.*, 2006; Qin and Enders, 2008)
- Select transition variable and transition function

Results nonlinearity tests

Trans. Var.	Clarida et al. (1998) F-test	Clarida et al. (1998) Trans. Funct.	Clarida et al. (1999) F-test	Clarida et al. (1999) Trans. Funct.	Orphanides (2003) F-test	Orphanides (2003) Trans. Funct.
π_{t-1}	0.59		0.69		1.32	
	0.84		*0.71*		*0.24*	
r_{t-1}	1.56		2.19	Exp.	2.16	Log.
	0.13		*0.04*		*0.03*	
π_{t+1}	1.42		1.63		0.81	
	0.19		*0.13*		*0.63*	
x_t	1.46		1.02		1.26	
	0.17		*0.44*		*0.27*	
$\sigma^2_{\pi,t}$	1.68	Log.**	2.3	Log.***	1.72	Log.**
	0.09		*0.03*		*0.09*	
VXO_t	2.36	Log.***	3.49	Log.***	1.52	
	0.02		*0.00*		*0.14*	

Note: π_{t-1} = annual inflation based on the GDP deflator at time *t-1*, π_{t+1}= expected annual inflation for period t+3 using information available until period *t*, r_{t-1} = federal funds rate at time *t-1*, x_t = output gap at time *t*, $\sigma^2_{\pi,t}$ = dispersion in the inflation outlook at time *t*, VXO_t = VXO volatility index at time *t*. The entries under F-test for each transition variable in the first column show the F-statistics and the associated p-values (in italics) for the null hypothesis of linear monetary policy reaction functions against the alternative of smooth transition regression. When the null hypothesis is rejected, the following column (Trans. Funct.) reports the transition function selected by a sequential F-test procedure (Teräsvirta, 2004). *Exp.* stands for the exponential transition function defined in Equation (3), while *Log.* stands for the Logistic function in Equation (4). The estimation sample spans the period from 1987Q4 to 2005Q4. In the case of the VXO volatility index the test is performed over a shorter sample starting in 1988Q1 due to near singularity of the moment matrix related to the high volatility induced by the financial market crash of October 1987.

Results nonlinearity tests (con't)

- Risk measures are more powerful driver of changes in monetary policy regimes
- Logistic function

Non-linear monetary policy reaction functions and risk management

- Estimate STR models using the two measures of risk as transition variable
- Non-linear least squares (NLLS)
- Two-step identification strategy:
  1. Fix value parameters in trans. function
  2. Grid search of these values

	Clarida *et al.* (1999)				Clarida *et al.* (1998)				Orphanides (2003)	
	$\sigma^2_{\pi,t}$		VXO_t		$\sigma^2_{\pi,t}$		VXO_t		$\sigma^2_{\pi,t}$	
Vector Ψ_0	**Estimate**	**Std. Err.**	**Estimate**	**Std. Err.**	**Estimate**	**Std. Err.**	**Estimate**	**Std. Err.**	**Estimate**	**Std. Err.**
Constant	0.32**	*0.14*	0.32**	*0.15*	0.24**	*0.10*	0.15	*0.11*	0.21	*0.15*
$\pi^e_{t\|t+3}$	0.61***	*0.10*	0.44***	*0.14*	0.46***	*0.08*	0.44***	*0.10*	0.53***	*0.07*
x_{t-1}									0.25***	*0.02*
x_t	0.23***	*0.02*	0.21***	*0.04*	0.14***	*0.03*	0.15***	*0.11*		
$x^e_{t\|t+3}$ - x_{t-1}									0.33***	*0.07*
r_{t-1}	0.65***	*0.04*	0.76***	*0.05*	1.22***	*0.09*	1.15***	*0.11*	0.72***	*0.04*
r_{t-2}					-0.48***	*0.07*	-0.38***	*0.09*		
Vector Ψ_1										
Constant	0.64	*0.48*	-0.19	*0.23*	0.88	*0.70*	0.14	*0.17*	0.70	*0.69*
$\pi^e_{t\|t+3}$	-0.38	*0.45*	0.30	*0.19*	-0.23	*0.59*	0.23	*0.23*	-0.31	*0.46*
x_{t-1}									0.20*	*0.11*
x_t	0.16**	*0.07*	0.17**	*0.07*	0.31***	*0.11*	0.17***	*0.04*		
$x^e_{t\|t+3}$ - x_{t-1}									-0.08	*0.17*
r_{t-1}	-0.18	*0.13*	-0.19**	*0.09*	-0.71***	*0.24*	-0.08	*0.17*	-0.22	*0.20*
r_{t-2}					0.44*	*0.23*	-0.09	*0.14*		
Transition function										
γ	2.47		3.01		2.9		6.35		3.25	
c	0.4		20.2		0.4		21		0.21	
Diagnostic tests										
Adj. R sqd.	0.98		0.98		0.99		0.99		0.98	
RMSE	0.29		0.29		0.29		0.23		0.29	
AIC	-2.28		-2.30		-2.68		-2.72		-2.29	
Autocorr. 1	26.3***		27.2***		1.22		1.26		14.8***	
Autocorr. 4	7.6***		7.3***		1.73		0.60		4.42***	
NRNL	0.62		1.67		0.62		0.86		1.06	

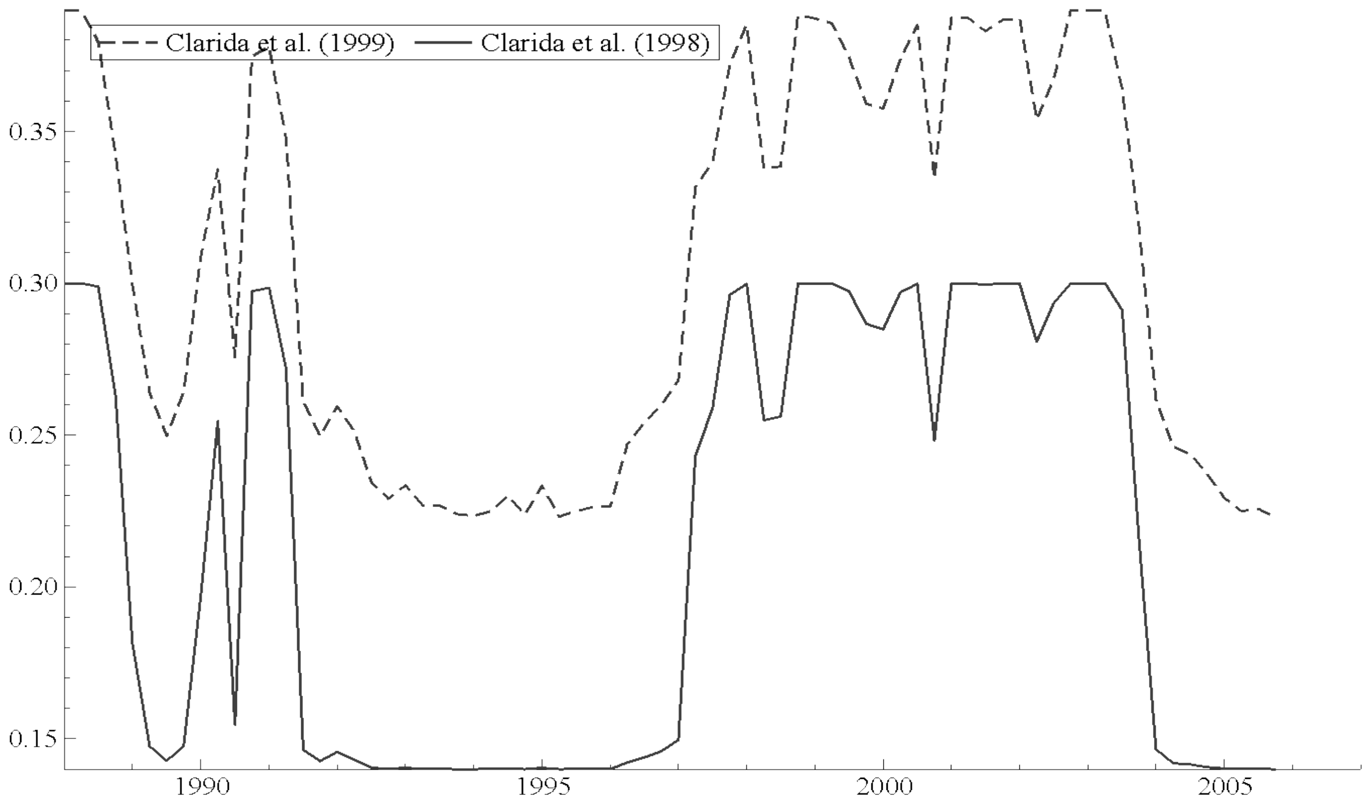
Note: $\pi^e_{t|t+3}$ = expected inflation between periods *t-1* and *t+3*, x_{t-i} = output gap for period *t-i*, for *i = 0,1*, $x^e_{t|t+3}$ = expected output gap for period *t+3*, r_{t-i} = Federal Funds rate at time *t-i*, for *i=1,2*. The transition variables are: $\sigma^2_{\pi,t}$ = dispersion in the inflation outlook at time *t*, and VOX_t = VXO volatility index at time *t*. Orphanides (2003) is estimated with one transition variable because linearity was not rejected for the VXO index. Models are estimated by NLLS using the Marquardt-Levenberg optimisation algorithm. The standard errors are based on the Newey-West heteroskedasticity and serial correlation robust estimator. The sample spans the period 1987Q4 to 2005Q4. In the case of the VXO volatility index the estimations are performed over a shorter sample starting in 1988Q1 (see note to Table 3). Autocorr. 1 and 4 denote the LM test for first and fourth order autocorrelation. NRNL is the F tests of no additive nonlinearity against an additive STR model. See Terasvirta (2004) for details regarding the autocorrelation and the NRNL test. (*), (**) and (***) denote significance at the 10, 5 and 1% levels, respectively.

Coefficients through time

- Output gap: $\varphi_t^* = \varphi_0^* + \varphi_1^* G(\gamma, c, s_t)$
- Inertia: $\rho_t = \sum_{j=1}^{J} \rho_{0j} + \sum_{j=1}^{J} \rho_{1j} G(\gamma, c, s_t)$
- For each model and each transition function
- The response of the US Fed to the inflation outlook is invariant across policy regimes

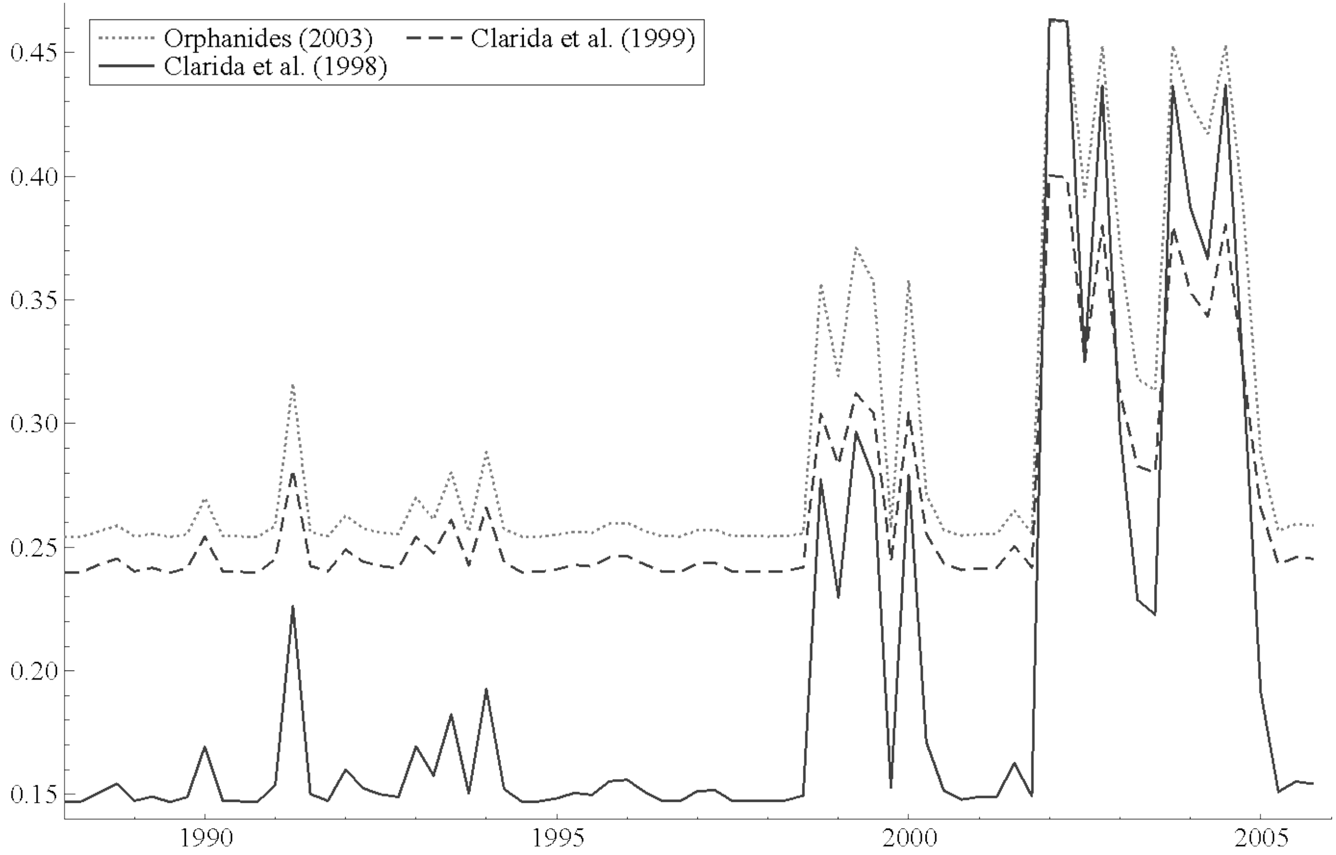
Output gap

A. VXO as transition variable:



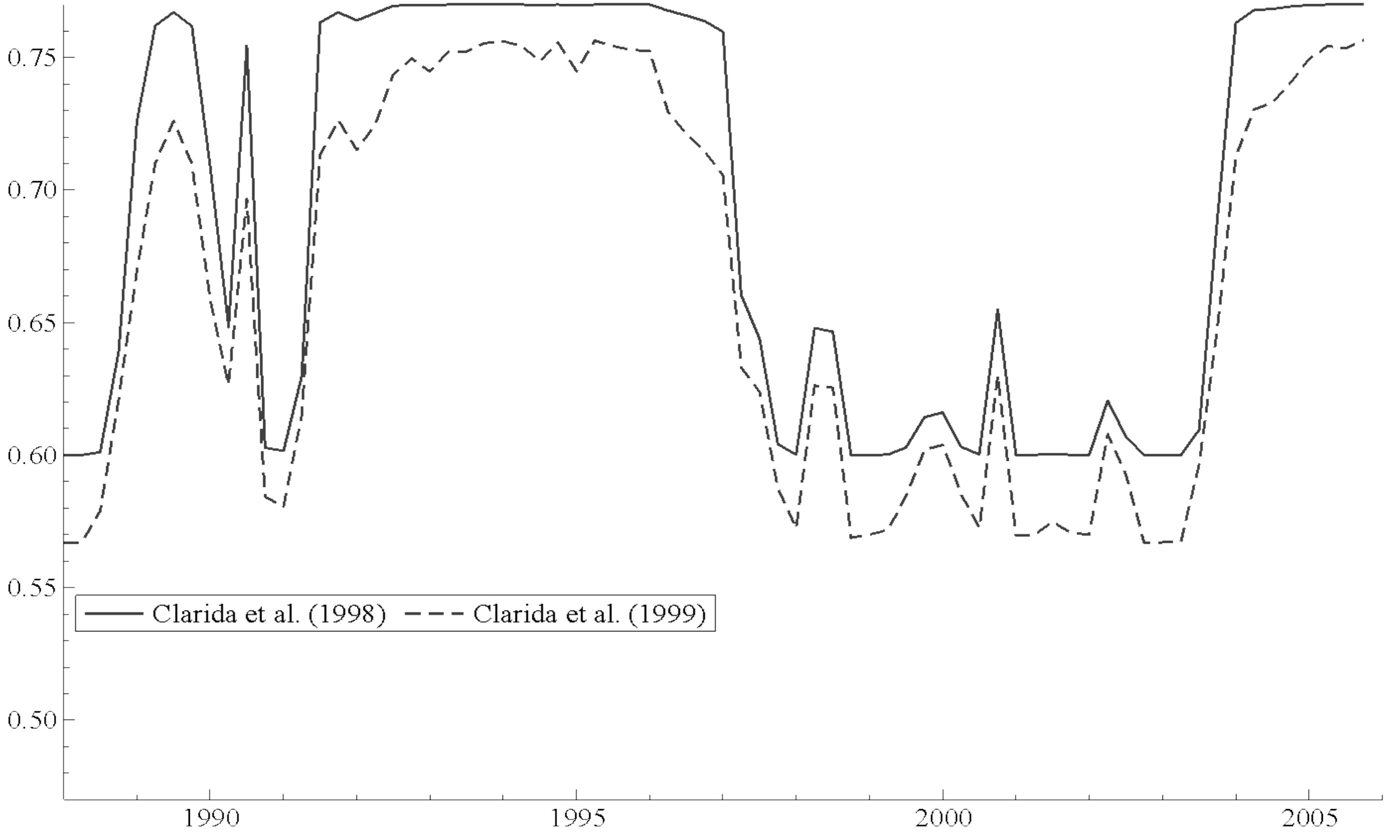
Output gap

B. Disp. in the inflation outlook:



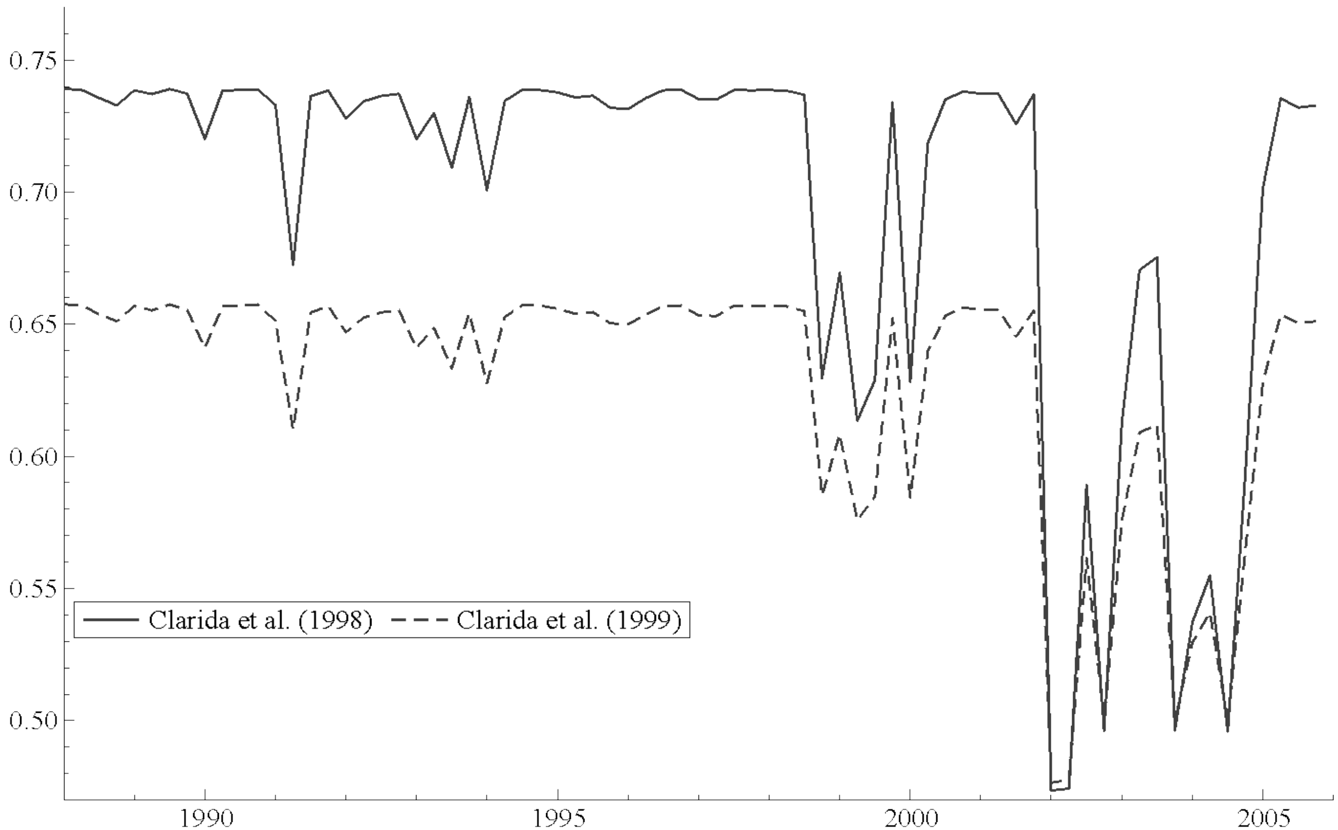
Inertia in monetary policy

A. VXO as transition variable:



Inertia in monetary policy

B. Disp. in the inflation outlook:



6. Conclusion

1. Risk measures are a more powerful driver of monetary policy regime changes
2. In periods of high risk, monetary policy tends to respond more aggressively to the output gap and the degree of inertia tends to be lower
3. The US Fed responded aggressively to output gap in late 1980s, early 1990s, second half of the 1990s and early 2000s.

Thank you!