Have the Preferences of the Fed Changed over Time? Evidence from a Structural Model*

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Abstract
We use a simple structural model based on the New Keynesian Phillips curve and an optimal targeting rule to estimate the preferences of the US Federal Reserve (Fed). Fed preferences are assumed to be quadratic and characterised by a target for inflation and relative weights for output gap smoothing and (possibly) interest rate smoothing. In line with a number of previous studies (Clarida, Gali and Gertler, 2000) we are interested in whether there was a change in the behaviour of the Fed with the appointment of Paul Volcker (and subsequent Chairs) and, if this change reflected a change in the Fed's preferences (Dennis, 2006). We find strong statistical evidence of a reduction in the Fed's inflation target with Volcker's appointment. In addition, it appears that there was also a decline in the relative weight the Fed gives to smoothing output gap fluctuations, but our estimates of this parameter typically have large standard errors, so we cannot draw this latter conclusion with the same degree of confidence as the first.

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1. Introduction

There is a debate in monetary economics about whether the behaviour of the United States Federal Reserve (Fed) changed at the end of the 1970s. The change is typically attributed to the appointment of Paul Volcker as Chair of the Fed. The Fed under Volcker (and later under Greenspan) is generally viewed as being tougher on inflation than it was in earlier periods. Evidence – for and against – a change in Fed behaviour is typically based on a Taylor rule (Taylor, 1993); where a change the Fed's behaviour is identified with a (large) change in the estimated coefficients for the rule – most notably the coefficient on inflation (Clarida, Gali and Gertler, 2000; Lubik and Schorfheide, 2003). Clarida, Gali and Gertler (CGG) estimate the coefficient on inflation in their Taylor rule to be 0.83 (significantly less than one) in the pre-Volcker period (60:1-79:2), and 2.15 (significantly greater then one) in the Volcker-Greenspan period (79:3-96:4). Similar results are obtained by Lubik and Schorfheide (2004) who use a Bayesian approach to estimate the Taylor rule as part of a small New Keynesian model. The implication of these findings is that the Fed was passive in responding to inflation in the pre-Volcker period – it raised the Federal Funds rate less than one-for-one with an increase in inflation – but switched to being active with the arrival of Volcker, after which it raised the Federal Funds rate more than one-for-one with an increase in inflation[1].

The use of a Taylor rule to draw inferences about the behaviour of the Fed is not without criticism (Dennis, 2006; Cochrane, 2007). An important issue concerns the interpretation of the Taylor rule. Under one interpretation it is simply a behavioural rule adopted by the Fed. The coefficients in the rule are true behavioural parameters that are "chosen" by the Fed: thus when CGG find the estimate of the coefficient on inflation increases from 0.83 to 2.15 this reflects a deliberate decision by the Fed to systematically move the Federal Funds rate by a greater amount in response to given changes in (expected) inflation. According to this view the parameters of the Taylor rule are structural.

The practice of closing an otherwise micro-founded New Keynesian model with a Taylor rule is relatively common and is consistent with a behavioural interpretation. Of course the treatment of the Fed as a "rule of thumb" actor is clearly at odds with the simultaneous treatment of the private sector as rational optimisers. However once the Fed is treated in a symmetric manner to the private sector – by specifying its preferences and assuming it optimises subject to the structure of the economy – its optimal interest rate rule will not

[1] Passive monetary policy leads to a violation of the Taylor principle – which requires the nominal policy rate to be increased sufficiently with a rise in inflation to ensure an increase in the real rate – and leads to a multiplicity of equilibria and a role for non-fundamental shocks in the New Keynesian model.

necessarily correspond to conventional (empirically-based) Taylor rule specifications. As Dennis (2006) (among others) points out, the coefficients in an optimally derived Taylor rule will be complicated functions of the Fed's preferences and other structural parameters in the economy. Thus in a world where the Fed is (or acts as if it is) a rational optimiser, we cannot entirely be sure that the results found by CGG do not simply reflect a change in the structure of the US economy (or a misperception of its structure by the Fed, see Orphanides (2003)).

In light of the above problem Dennis (2006) advocates modelling the Fed's behaviour by specifying its objective function and then deriving its optimal interest rate rule, conditional on a particular model for the US economy. The Fed's interest rate rule can be estimated jointly with the structural model, imposing any cross-equation restrictions. This approach allows the Fed's preference parameters to be identified and to examine whether they actually change over time. Under this approach if we want to talk about a change in Fed behaviour – say at the end of the 1970s – this really amounts to saying there is a change in parameters in the Fed's objective function.

Dennis uses the structural approach to examine if there has been a change in Fed preferences. Like CGG he considers two sub-periods, pre-Volcker (66:1 – 79:3) and Volcker-Greenspan (82:1-00:2). The Fed is assumed to have a quadratic loss function characterised by three parameters: an inflation target π^*; a weight on output gap stabilisation λ and a weight on interest rate stabilisation ν (where the two weights are relative to stabilisation of inflation around the target). A formal test for the stability of $\{\pi^*, \lambda, \nu\}$ over the full sample period (66:1-00:2) is rejected, suggesting there has been some change in Fed preferences. Comparing Dennis's estimates of these parameters between the two sample periods we observe a marked decline in the estimated (annual) inflation target from 7 to 1.4 percent. There is also a large fall in the estimated interest rate smoothing parameter – from about 37 to 4.5. What is less evident is whether the weight the Fed gives to output gap stabilisation has changed; the point estimates are 3.1 (pre-Volcker) and 2.9 for the Volcker-Greenspan era. While the point estimate falls marginally, in neither sample period is the estimate of λ statistically significant.

Favero and Rovelli (2003) also examine the stability of Fed preferences. Like Dennis they model Fed preferences with a quadratic loss function, however rather than solving for the optimal interest rate rule, Favero and Rovelli use the Fed's first-order condition – its Euler equation – along with a structural model of the economy, to estimate Fed preferences. They estimate their model for a pre-Volcker sample period (1961:1-1979:2) and a Volcker-

Greenspan sample (1980:3-1998:3). Their estimate of π^* declines from 5.8 to 2.6 percent across the two samples, which is broadly in line with the results by Dennis. Interestingly Favero and Rovelli's estimates of λ and ν are of a very different order of magnitude to those by Dennis: $\hat{\lambda}$ is 0.00153 (pre-Volcker) and 0.00125 (Volcker-Greenspan); while $\hat{\nu}$ is 0.0051 and 0.0085 for the respective regimes. All parameter estimates are statistically significant. According to these estimates the weight given to interest smoothing by the Fed actually increased in the Volcker-Greenspan era. However the estimates do suggest a decline in the Fed's relative preference for output gap stabilisation in the Volcker-Greenspan era. The percentage fall is about 18 percent, which can be compared to decline of 6.5 percent implied by Dennis's point estimates. Favero and Rovelli do not report formal tests for the stability of the Fed's preference parameters.

In this paper we adopt the basic approach to Dennis and Favero and Rovelli in modelling the behaviour of the Fed. We approximate the preferences of the Fed with a quadratic loss function. In our baseline model we assume the Fed only cares about deviations of inflation (around some target) and in deviations in the output gap (Svennson, 2003). However in a generalisation of the baseline model also consider a loss function where the Fed has a preference for smoothing the Federal Funds rate. The main difference between our analysis and previous work lies with the structure of our model for the US economy. In their studies both Dennis and Favero and Rovelli use a purely backward-looking model of the US economy due to Rudebusch and Svensson (1999)[2]. In contrast we emphasise the forward-looking behaviour by the private sector that is a defining element of the New Keynesian model. Thus in our baseline model the Fed optimises subject to the forward-looking New Keynesian Phillips curve. In an extension to this model we also consider the hybrid form of the Phillips curve (Fuhrer and Moore, 1995). In seeking to estimate the Fed's preferences (and other structural parameters) we follow Favero and Rovelli and work with the Euler equation for optimal policy and the Phillips curve. The choice of loss function and forward-looking Phillips curve implies that our Euler equation for the Fed is a simple example of the flexible forecast targeting rule advocated by Svennson (2003) and Woodford (2007).

In light of the forward-looking behaviour by the private sector we need to male an assumption about whether the Fed engages in purely discretionary behaviour – and hence gives up any hope of being able to influence private sector expectations – or whether it seeks

[2] Dennis (2004) uses a forward-looking New Keynesian model for the US and derives and estimates the optimal interest rate rule jointly with the economic model. However his estimates of the Fed's preferences are broadly similar to those in Dennis (2006).

to implement a policy that is consistent with optimisation under commitment. Since all central banks appear to be concerned with influencing expectations we chose to examine the Fed's Euler equation (targeting rule) under commitment. Woodford (2007) discusses the potential benefits of the commitment solution over the discretionary solution.

The paper has the following outline. In Sections 2 we present some results obtained from re-estimating CGG's Taylor rule using a recent data vintage. In general our estimates are largely consistent with those obtained by CGG. In Section 3 we report the estimates of Fed preferences based on our baseline targeting-rule and Phillips curve model. We then report the results of a series of robustness tests and extensions to the baseline model. Section 4 concludes.

2. Estimates of CGG's Taylor rule

Given the importance of CGG's original findings in the debate about whether the behaviour of the Fed has changed, we begin by establishing whether or not their conclusions hold-up using recent data. The baseline Taylor rule estimated by CGG can be written as the following moment condition:

$$E\{[r_t-(1-\rho)(rr^*-(\beta-1)\pi^*+\beta\pi_{t,t+1}+\gamma x_{t,t+1})+\rho_1 r_{t-1}+(\rho-\rho_1)r_{t-2}]\mathbf{z_t}\}=0 \qquad (1)$$

where r is the nominal Federal Funds rate, rr^* is the long-run equilibrium real rate ($\equiv r^*-\pi^*$), π^* is the target inflation rate, $\pi_{t,t+1}$ is the percentage change in prices between t and $t+1$ and $x_{t,t+1}$ is the real output between t and $t+1$. E is the expectation operator and $\mathbf{z_t}$ is a vector of instruments observed by the Fed when r_t is set. If a value for rr^* is imposed on (1) then the remaining parameters $\{\pi^*,\beta,\gamma,\rho,\rho_1\}$ can be estimated using GMM.

We re-estimate CGG's forward-looking Taylor rule using a recently available vintage of data. Our data sample ends in 2009:1 (this data vintage was released 25/6/2009). The initial set of estimates corresponds to the two sample periods used by CGG; (60:1-79:2) and (79:3-96:4). We follow CGG in the choice of instruments and use lags 1 to 4 of: inflation; output gap; FF rate; spread between short and long rates and commodity price inflation[3].

Table 1 shows the original estimates from CGG and the estimates we obtain using the newer vintage of data. The estimates from the recent data vintage are qualitatively similar to those obtained by CGG. The point estimate for β in the pre-Volcker era is less than one (0.9); whereas it is estimated to be substantially greater than one (2.49) in the post-Volcker period. There is clearly a large difference between these estimates of β in the two sample

[3] This is a relatively large number of instruments and one might reasonably be concerned about over-fitting. However we find that using only two lags makes little difference to the results.

periods used by CGG. However from a formal statistical perspective there is some difference between our results and those of CGG. Using the results reported by CGG it is possible to reject the hypothesis that β=1 in favour of the alternative that β<1 at about the 1 percent level of significance. Using our estimates the same hypothesis is only rejected at about the 10 percent level. It could be argued that with the recent data vintage the evidence that the Fed behaved in passive manner – in the pre-Volcker period – is somewhat weaker.

Table 1: Estimates of CGG's Taylor Rule

$$E\{[r_t - (1-\rho)(rr^* - (\beta - 1)\pi^* + \beta\pi_{t,t+1} + \gamma x_{t,t+1}) + \rho_1 r_{t-1} + (\rho - \rho_1) r_{t-2}]\mathbf{z_t}\} = 0$$

	π^*	β	γ	ρ	J
			CGG Estimates		
60:1 – 79:2	4.24 (1.09)	0.83 (0.07)	0.27 (0.08)	0.68 (0.05)	0.83
79:3 – 96:4	3.58 (0.50)	2.15 (0.40)	0.93 (0.42)	0.79 (0.04)	0.32
			Estimates with New Data Vintage		
CGG Sample 60:1 – 79:2	5.48 (2.74)	0.90 (0.08)	0.23 (0.10)	0.77 (0.04)	0.79
79:3 – 96:4	2.31 (0.54)	2.49 (0.41)	1.66 (0.70)	0.84 (0.04)	0.77
Updated Sample 79:3 – 08:4	2.86 (0.38)	2.56 (0.81)	1.37 (0.41)	0.89 (0.02)	0.39

Notes: Estimation by GMM. Instruments are lags 1 to 4 of: inflation; output gap; Fed Funds rate; spread between short and long rates and commodity price inflation. J is the p-value for Hansen's J-statistic for over-identification. Standard errors are in brackets.

Using the updated sample from 1979:3 to 20008:4 produces estimates that qualitatively consistent with CGG's results. This specification of the Taylor rule appears to be remarkably stable over the Volcker-Greenspan-Bernanke eras. Despite this, the question as to how to interpret the β (and γ) parameters in the Taylor rule still arises. We cannot be really certain that the increase in magnitude of both β and γ – between the two sample periods – does not reflect some change in the structure of the US economy, rather than a change in the behaviour of the Fed. It is to this issue that we now turn.

3. Structural Estimates of Fed Preferences

Baseline Model

We assume that the main objectives of the Fed can be adequately approximated by a quadratic function of inflation and the output gap.

$$L_t = E_t \sum_{i=0}^{\infty} \theta^{t+i} \left\{ (\pi_{t+i} - \pi^*)^2 + \lambda x_{t+i}^2 \right\} \tag{2}$$

The only effective constraint on the Fed's behaviour is a standard New Keynesian Phillips curve,

$$\pi_t = \theta E_t \pi_{t+1} + \phi x_t + v_t \tag{3}$$

If the Fed seeks to implement optimal policy that is consistent with Woodford's (2004) timeless commitment solution, its Euler equation is given by

$$E_t[(\pi_{t+i} - \pi^*) + \frac{\lambda}{\phi} \Delta x_{t+i}] = 0 \quad \text{for all } i \geq 0 \tag{4}$$

Equation (4) is an example of a flexible forecast targeting rule (Svensson 2003; Woodford 2007). Notice that the exact means by with the Fed achieves its target does not need to be specified. However, an (optimal) policy rule for the Fed could be obtained for the above model by using the New Keynesian IS curve along with equations (3) and (4), to obtain an equation linking interest rates to inflation (and possibly the output gap).

Rather than working with the optimal interest rate rule we seek to estimate the structural parameters of the model by jointly estimating equations (3) and (4) – the Phillips curve and Fed's targeting rule. While our model implies that (4) should hold for all $i \geq 0$, to estimate the model we focus on a single horizon for the targeting rule and choose $i = 2$ (quarters). This allows for the fact that the Fed is not immediately able to influence inflation and output using its policy instrument[4].

The baseline model we estimate is given by;

$$\pi_t = \mu + \theta E_t \pi_{t+1} + \phi x_t + v_t \tag{5}$$

$$E_t[(\pi_{t+2} - \pi^*) + \frac{\lambda}{\phi} \Delta x_{t+2}] = 0 \tag{6}$$

where we have included a constant term to the Phillips Curve. If we estimate the above equations as a system, then we can identify the Fed's preference parameters for output stabilisation λ and their inflation target π^*. We can then examine if either parameter has

[4] We investigate the robustness of our results to setting $i = 4$.

changed over time; and we follow CGG by focusing on pre and post-Volcker periods. Otto and Voss (2009) estimate the second equation above (the targeting rule) for the US, but are not able to separately identify λ and γ. We estimate the two equations using GMM; separately and then as a system with the cross-equation restrictions imposed.

Data Issues

To estimate equations (5) and (6) we use quarterly US data for the period 1960:1 to 2008:2. In defining the variables for the Phillips curve, and in choosing instruments, we follow the approach of CGG (2005). Inflation is measured using the CPI, while in the Phillips curve we use the (log of) labour share of income $[(W \times N)/Y]$ as the proxy for marginal cost in place of x (the output gap). In (6) we need a measure of the change in the output gap and to obtain this variable we measure the output gap x as the residual from regressing the log of GDP on a constant, time and time squared for the period 55:1 to 08:2. The instruments used are a constant, and lags 1 to 4 of inflation, the output gap, wage inflation and log wage share.

Table 2 reports the results from estimating (5) and (6) individually and then jointly using GMM. We report estimates for three sample periods: pre-Volcker (60:1 – 79:2) and then 79:3 – 96:4 (CGG's sample) and finally for 79:3 – 07:4. The single equation estimates of the Phillips curve and the targeting rule are reasonable across all three samples. In the case of the Phillips curve, the weight on future inflation is positive (ranging from 0.87 to 0.93) and statistically significant. The estimate on marginal cost is positive, although with a reasonably large standard error. The estimates for the targeting rule are particularly interesting. First the simple targeting rule appears to work well over the entire sample period – albeit with some possible changes in its parameters. This finding is consistent with the (surprising) conclusion that the Fed has been pursuing a policy of flexible inflation targeting (with commitment) at least since the beginning of the 1960s. In the pre-Volker era the Fed's inflation target is estimated at about 4.5 percent per annum, while the weight it gives to the change in the output gap in its targeting rule is estimated to be about 0.88. Notice that if the weight were unity Fed would be approximately targeting (forecast) nominal GDP[5]. For the sample that begins with the appointment of Volcker, the estimated inflation target falls (to about 2.5 percent) and the weight on the output gap changes in the targeting rule (to about 0.5/0.6). In on sense the targeting rule tells a similar story to CGG's Taylor rule. Of course with the single equation estimates of the targeting rule alone it is not possible to say what has caused the decline in weight on Δx – in particular whether it was due to a fall in the value of λ.

[5] Aside from the fact that it has zero mean, Δx is very similar to the real output growth (the contemporaneous correlation is 0.995).

However if we are willing to use the single equation estimates of ϕ from the Phillips curve, then the implied estimate of λ is 4.6 over the 60:1 – 79:2 sample and 3 over the 79:3 – 07:4 sample.

Table 2: Forward-Looking Phillips Curve and Targeting Rule

$$\pi_t = \mu + \theta E_t \pi_{t+1} + \phi x_t + v_t$$
$$E_t[(\pi_{t+2} - \pi^*) + \frac{\lambda}{\phi}\Delta x_{t+2}] = 0$$

	π^*	μ	θ	ϕ	λ	$\frac{\lambda}{\phi}$	J
				Single Equation Estimates			
Phillips Curve							
60:1 – 79:2	-	-24.19	0.93	5.23	-	-	0.53
		(29.33)	(0.03)	(6.34)			
79:3 – 96:4	-	-35.04	0.87	7.69	-	-	0.57
		(23.49)	(0.07)	(5.13)			
79:3 – 07:4	-	-22.23	0.87	4.89	-	-	0.28
		(16.54)	(0.06)	(3.61)			
Targeting Rule							
60:1 – 79:2	4.44	-	-	-	-	0.88	0.45
	(0.33)					(0.12)	
79:3 – 96:4	2.49	-	-	-	-	0.52	0.45
	(0.12)					(0.07)	
79:3 – 07:4	2.55	-	-	-	-	0.61	0.58
	(0.12)					(0.11)	
				System Estimates			
60:1 – 79:2	4.54	-45.01	0.85	9.79	8.25	-	0.23
	(0.25)	(27.66)	(0.03)	(5.98)	(5.07)		
79:3 – 96:4	2.55	-49.17	0.86	10.74	5.72	-	0.41
	(0.09)	(24.02)	(0.05)	(5.24)	(2.75)		
79:3 – 07:4	2.53	-32.96	0.88	7.21	4.15	-	0.30
	(0.10)	(18.58)	(0.04)	(4.05)	(2.32)		

Notes: Estimation by GMM. Instruments are lags 1 to 4 of: inflation; output gap; wage inflation and (log) wage share. J is the p-value for Hansen's J-statistic for over-identification. Standard errors are in brackets.

Joint estimation of the Phillips curve and the targeting rule allows for the separate identification of both λ and ϕ. The systems estimates of the structural parameters appear reasonable. We can see that the relative weight the Fed gives to stabilising the output gap appears to have declined with the appointment of Volcker (and subsequent Fed Chairs). Between the pre-Volcker and Volcker-Greenspan-Bernanke eras the estimate of λ falls by about a half (from about 8 to 4). In addition as was observed from the estimates of the targeting rule there also appears to be a decline in the Fed's inflation target, from about 4.5 to about 2.5.

While the point estimates in Table 2 suggest there was a change in Fed preferences with the appointment of Volcker, we need to consider a formal test of this claim. To do this we focus on the system estimates and define a dummy variable D97 that is zero from 60:1 – 79:2 and one afterwards. This dummy is interacted with all of the variables in equations (5) and (6), then the model is estimated over the full sample 61:1 – 07:4 and the significance of the coefficients on the interaction terms is examined. The main results are reported in Table 3.

Table 3: Forward-Looking Phillips Curve and Targeting Rule - Stability Tests

	π^*	μ	θ	ϕ	λ	J
Full Sample						
60:1 – 07:4	3.05	-17.19	0.91	3.76	3.82	0.19
	(0.18)	(15.84)	(0.04)	(3.44)	(3.45)	
Interaction Terms						
	$\pi^* + D79$	$\mu + D79$	$\theta + D79$	$\phi + D79$	$\lambda + D79$	
Instrument Set No.1	-1.76	164.92	-0.29	-35.33	-19.93	
	(0.32)	(122.45)	(0.31)	(26.43)	(23.38)	
Instrument Set No.2	-1.80	53.61	-0.04	-11.56	5.73	
	(0.39)	(60.48)	(0.06)	(13.09)	(6.99)	
Instrument Set No.1	-1.83	-	-	-	1.81	
	(0.32)				(2.49)	
Instrument Set No.1	-1.65	-	-	-	-	
	(0.32)					

Notes: Estimation by GMM. Instrument Set No.1 is lags 1 to 4 of: inflation; output gap; wage inflation and (log) wage share. Instrument Set No.2 is lags 1 to 2 of: inflation; output gap; wage inflation; (log) wage share and the same variables multiplied by the sub-period dummy. J is the p-value for Hansen's J-statistic for over-identification. Standard errors are in brackets.

The parameter stability tests in Table 3 suggest that the only parameter to change in 1979 is the Fed's target for inflation. None of the other interaction dummies are found to be statistically significant. In particular the fall in the point estimate of λ is not identified by the test to be statistically significant.

Robustness Checks

While the J-statistics reported in Table 1 do not indicate any misspecification of the model, it is often the case that the J-test can have low power. Thus we consider whether the findings for this baseline model are robust to certain modelling choices. We focus on the system estimates and results of the robustness tests are presented in Table 4.

Table 4: Forward-Looking Phillips Curve and Targeting Rule – Robustness

	π^*	μ	θ	ϕ	λ	J
			System Estimates			
Targeting Rule Horizon i=4						
60:1 – 79:2	4.51	-68.88	0.89	14.95	11.11	0.19
	(0.28)	(28.76)	(0.04)	(6.22)	(4.96)	
79:3 – 96:4	2.69	-45.54	0.96	9.94	5.73	0.14
	(0.13)	(17.71)	(0.04)	(3.86)	(2.41)	
79:3 – 07:2	2.50	-47.52	1.00	10.33	5.69	0.28
	(0.10)	(18.95)	(0.04)	(4.13)	(2.44)	
Targeting Rule Normalized on Δx_{t+2}						
60:1 – 79:2	4.10	-33.85	0.80	7.40	10.66	0.25
	(0.41)	(27.05)	(0.03)	(5.85)	(8.38)	
79:3 – 96:4	2.54	-42.70	0.87	9.34	5.50	0.42
	(0.11)	(24.00)	(0.05)	(5.22)	(3.04)	
79:3 – 07:2	2.65	-27.80	0.90	6.09	5.49	0.35
	(0.15)	(18.66)	(0.04)	(4.07)	(3.68)	
Newey-West Estimator (lag=1)						
60:1 – 79:2	4.64	6.54	0.86	-1.38	-1.15	0.60
	(0.24)	(24.19)	(0.03)	(5.23)	(4.35)	
79:3 – 96:4	2.49	-41.43	0.82	9.10	5.01	0.85
	(0.09)	(17.50)	(0.04)	(2.38)	(2.07)	
79:3 – 07:2	2.56	-12.37	0.86	2.75	1.73	0.70
	(0.10)	(15.29)	(0.04)	(3.34)	(2.09)	
Nonlinear Least Squares Estimator						
60:1 – 79:2	4.65	-18.42	0.82	4.14	0.81	-
	(0.30)	(30.85)	(0.06)	(6.66)	(1.39)	
79:3 – 96:4	3.57	-67.28	0.67	14.87	1.92	-
	(0.25)	(27.70)	(0.10)	(5.94)	(1.61)	
79:3 – 07:2	3.06	-37.43	0.66	8.36	1.14	-
	(0.17)	(18.59)	(0.08)	(4.06)	(0.92)	

Notes: The first three models are estimated by GMM. Instruments are lags 1 to 4 of: inflation; output gap; wage inflation and (log) wage share. J is the p-value for Hansen's J-statistic for over-identification. Standard errors are in brackets.

The first block of Table 4 shows the effect of using a one year horizon (*i=4)* for the targeting rule. The estimates are generally consistent with those for *i=2*, although interestingly the standard errors for the estimates of ϕ and λ are smaller when *i=4*. The second set of results looks at the impact of re-normalizing the targeting rule so that the parameter to be estimated is on inflation, rather than on the change in the output gap. Since we are instrumenting variables three periods ahead (of $\mathbf{z_{t-1}}$) in the targeting rule, it is important to minimize the potential for weak instruments. However the estimates are essentially robust to this re-normalization. In the third block of the table we report GMM estimates that allow for an MA(1) process in the errors of the structural equations. Doing so leads to negative point estimates for ϕ and λ in the pre-Volcker period. Finally we report the estimates that are obtained by ignoring the potential for correlation between the model errors and the variables in the model, and using non-linear least squares (NLS). We view this as providing an indication as to the gain from using an instrumental variable estimator, and more importantly, since we use a relatively large number of instruments, whether we are tending to overfit the data. If the latter is the case we might expect our GMM estimates not to differ much from the NLS estimates. In fact there are quite large differences between the two sets of estimates, particular with respect to the λ.

A Hybrid Phillips Curve

Traditional models of inflation point to an important role for lagged inflation (Rudd and Whelan, 2005). This has led to the widespread use of the hybrid Phillips curve, which contains both a backward and a forward-looking component for inflation. Gali and Gertler (1999) and Gali, Gertler and Lopez-Salido (2005) provide empirical evidence that the hybrid Phillips curve is a good model for US data. If we replace (3) by equation (7) below, this changes the form of the Fed's targeting rule and our system has the following form:

$$\pi_t = \mu + \theta E_t \pi_{t+1} + (1-\theta)\pi_{t-1} + \phi x_t + v_t \qquad (7)$$

$$E_t[(\pi_{t+2} - \pi^*) + \frac{\lambda\theta}{\phi}\Delta x_{t+2} - \frac{\lambda(1-\theta)}{\phi}\Delta x_{t+3}] = 0 \qquad (8)$$

Notice there are new variables in the model, but no additional parameters. Table 5 reports the estimates of the above system.

Looking at the single equation estimates we obtain an estimate of the weight on lagged inflation of about 0.3 to 0.4 – depending on the sample – which is similar to the GMM estimate reported by Gali, Gertler and Lopez-Salido. The point estimates for ϕ tends to fall in the later two data samples, and all the estimates have large standard errors (as found for the baseline case). We obtain reasonable estimates for the targeting rule, with the coefficient on Δx_{t+3} estimated to be negative.

Table 5: Forward and Backward-Looking Phillips Curve and Targeting Rule

$$\pi_t = \mu + \theta E_t \pi_{t+1} + (1-\theta)\pi_{t-1} + \phi x_t + v_t$$
$$E_t[(\pi_{t+2} - \pi^*) + \frac{\lambda\theta}{\phi}\Delta x_{t+2} - \frac{\lambda(1-\theta)}{\phi}\Delta x_{t+3}] = 0$$

	π^*	μ	θ	ϕ	λ	$\frac{\lambda\theta}{\phi}$	$\frac{\lambda(1-\theta)}{\phi}$	J
				Single Equation Estimates				
Phillips Curve								
60:1 – 79:2	-	-21.83	0.61	4.71	-	-	-	0.60
		(19.83)	(0.07)	(4.29)				
79:3 – 96:4	-	- 6.77	0.65	1.46	-	-	-	0.35
		(11.83)	(0.10)	(2.57)				
79:3 – 07:3	-	- 7.23	0.71	1.56	-	-	-	0.22
		(11.68)	(0.09)	(2.54)				
Targeting Rule								
60:1 – 79:2	4.47	-	-	-	-	0.64	0.27	0.43
	(0.33)					(0.22)	(0.28)	
79:3 – 96:4	2.75	-	-	-	-	0.42	0.50	0.66
	(0.19)					(0.10)	(0.13)	
79:3 – 07:3	2.69	-	-	-	-	0.43	0.51	0.81
	(0.16)					(0.14)	(0.18)	
				System Estimates				
60:1 – 79:2	4.30	-50.75	0.75	10.95	10.91	-	-	0.08
	(0.25)	(21.51)	(0.06)	(4.65)	(5.50)			
79:3 – 96:4	2.53	23.54	1.09	- 2.43	- 5.14	-	-	0.39
	(0.09)	(17.68)	(0.10)	(1.97)	(3.83)			
79:3 – 07:3	2.58	- 0.47	1.02	0.07	0.04	-	-	0.21
	(0.10)	(15.23)	(0.09)	(3.30)	(1.82)			

Notes: Estimation by GMM. Instruments are lags 1 to 4 of: inflation; output gap; wage inflation and (log) wage share. J is the p-value for Hansen's J-statistic for over-identification. Standard errors are in brackets.

For the system estimates the hybrid model seems to work well during the pre-Volcker period and in fact produces parameter estimates that are broadly similar to those from the baseline model. The estimates of π^* are very similar to the baseline model, while the estimate of λ is somewhat larger in the hybrid model; 11 compared to 8 in the baseline model. However the hybrid model runs into problems when it is estimated on data for the later two samples. Using the sample 79:3 – 96:4 we obtain negative point estimates for both λ and ϕ and an estimate of θ greater than 1 (implying a negative coefficient on lagged inflation). With the longer sample (79:3 – 07:3) the estimated values of λ and ϕ are both very small and not statistically different from zero. One response to these results might be to use the hybrid Phillips curve for the pre-Volcker period and then use the forward-looking Phillips curve for the Volcker-Greenspan-Bernanke period. This would imply that there had been a change in private sector behaviour between these two periods. However, even if this is the case it does not really alter the basic story about the behaviour of Fed preferences over the full sample. Both the baseline and the hybrid models point to a fall in the Fed's inflation target after Volcker's appointment. Furthermore both models suggest that the Fed gave greater weight to stabilising the output gap in the pre-Volcker era.

Interest Rate Smoothing

We now turn to the vexing (for us) issue of interest rate smoothing. There is an on-going debate about whether the Fed (and other central banks) smooth the policy rate. While the relatively large values of values of ρ obtained in CGG's (and other) estimates of the Taylor rule is frequently taken as evidence of smoothing behaviour, a number of authors have argued against smoothing behaviour (Rudebusch, 2002; Consolo and Favero, 2009). However if the Fed does have a preference for smoothing the Federal Funds rate, then our targeting rules (6) and (8) will be misspecified; with the usual implications of inconsistent coefficient estimates.

An obvious way to address this issue is to augment the Fed's loss function with a term in the (squared) change in the Federal Funds rate and incorporate the New Keynesian IS curve (11) into the Fed's optimisation problem, as follows:

$$L_t = E_t \sum_{i=0}^{\infty} \theta^{t+i} \left\{ (\pi_{t+i} - \pi^*)^2 + \lambda x_{t+i}^2 + \lambda_i (i_{t+i} - i_{t+i-1})^2 \right\} \tag{9}$$

$$\pi_t = \theta E_t \pi_{t+1} + \phi x_t + v_t \tag{10}$$

$$x_t = E_t x_{t+1} - \sigma(i_t - E_t \pi_{t+1}) + \omega_t \tag{11}$$

To derive the Fed's targeting rule we set-up the Lagrangian;

$$\Lambda_t = \frac{1}{2} E_t \sum_{i=0}^{\infty} \theta^{t+i} \left\{ \begin{aligned} &(\pi_{t+i} - \pi^*)^2 + \lambda x_{t+i}^2 + \lambda_i (i_{t+i} - i_{t+i-1})^2 + 2\psi_{1,t+i}[\pi_{t+i} - \theta \pi_{t+i+1} - \phi x_{t+i} - v_{t+i}] \\ &+ 2\psi_{2,t+i}[x_{t+i} - x_{t+i+1} + \sigma(i_{t+i} - \pi_{t+i+1}) - \omega_{t+i}] \end{aligned} \right\} \tag{12}$$

and using Woodford's timeless solution we can just focus of the first-order conditions for $i \geq 1$.

$$\frac{\partial \Lambda_t}{\partial \pi_{t+i}} = \theta(\pi_{t+i} - \pi^*) + \theta \psi_{1,t+i} - \theta \psi_{1,t+i-1} - \sigma \psi_{2,t+i-1} = 0 \tag{13}$$

$$\frac{\partial \Lambda_t}{\partial x_{t+i}} = \theta \lambda x_{t+i} - \theta \phi \psi_{1,t+i} + \theta \psi_{2,t+i} - \psi_{2,t+i-1} = 0 \tag{14}$$

$$\frac{\partial \Lambda_t}{\partial i_{t+i}} = \lambda_i(i_{t+i} - i_{t+i-1}) + \sigma\psi_{2,t+i} - \theta\lambda_i E_t(i_{t+i+1} - i_{t+i}) = 0 \tag{15}$$

Solving these equations leads to a relatively complicated targeting rule for the Fed. To see this combine the first two conditions to obtain for $i = 1$;

$$(\pi_{t+i} - \pi^*) + \frac{\lambda}{\phi}\Delta x_{t+1} + \phi^{-1}\Delta\psi_{2,t+1} - \phi^{-1}(\psi_{2,t} - \theta^{-1}\psi_{2,t-1}) - \sigma\theta^{-1}\psi_{2,t} = 0 \tag{16}$$

and while we could use (15) to substitute out the Lagrange multiplier, the resulting targeting rule would be a very complicated function of $i_{t-2},.....,i_{t+2}$. This is no longer a simple targeting rule and is likely to be difficult to estimate. It is worth nothing that things are considerably simpler under discretionary optimisation as the lagged Lagrange multipliers disappear (since bygones are bygones) and the Euler equation would becomes;

$$(\pi_{t+i} - \pi^*) + \frac{\lambda}{\phi}x_{t+1} + \phi^{-1}\psi_{2,t+1} = 0 \tag{17}$$

with the multiplier given by (15).

Finally a somewhat simpler targeting rule can be obtained by using a loss function in which the Fed cares about deviations of the Federal Funds rate around some (exogenous) target value, Woodford (2002):

$$L_t = E_t\sum_{i=0}^{\infty}\theta^{t+i}\left\{(\pi_{t+i} - \pi^*)^2 + \lambda x_{t+i}^2 + \lambda_i(i_{t+i} - i_{t+i}^*)^2\right\} \tag{18}$$

With this loss function the first-order condition (15) becomes;

$$\frac{\partial \Lambda_t}{\partial i_{t+i}} = \lambda_i(i_{t+i} - i_{t+i}^*) + \sigma\psi_{2,t+i} = 0 \tag{19}$$

and we get a somewhat simpler target rule, that only depends on $i_{t-1},....,i_{t+1}$.

To test our baseline and hybrid models in the direction of interest rate smoothing we consider targeting rules of the following form:

$$E_t[(\pi_{t+2} - \pi^*) + \frac{\lambda}{\phi}\Delta x_{t+2} + \kappa_1\Delta i_{t+i} + \kappa_2\Delta i_{t+2}] = 0 \tag{20}$$

$$E_t[(\pi_{t+2} - \pi^*) + \frac{\lambda\theta}{\phi}\Delta x_{t+2} - \frac{\lambda(1-\theta)}{\phi}\Delta x_{t+3} + \kappa_1\Delta i_{t+1} + \kappa_2\Delta i_{t+2}] = 0 \tag{21}$$

and while these are admittedly ad hoc, but we view their use as a specification test based on variable addition . Does the addition of interest rate changes change our conclusions about π^* and λ? Interestingly a targeting rule like (20) begins to look somewhat like CCG's Taylor rule. The main differences being the inclusion of the change in the output gap rather than the level and the change rather than the level of the Federal Funds rate.

Table 6 presents the systems estimates for the models using (20) and (21). For most sample periods at least one of the interest rate terms is found to be statistically significant. Despite this, the inclusion of the interest rate terms in the targeting rules does not alter our basic finding that there was a decline in π^* and λ with the appointment of Paul Volcker.

Table 6: Tests for Interest Rate Smoothing

$$E_t[(\pi_{t+2} - \pi^*) + \frac{\lambda}{\phi}\Delta x_{t+2} + \kappa_1 \Delta i_{t+i} + \kappa_2 \Delta i_{t+2}] = 0$$

$$E_t[(\pi_{t+2} - \pi^*) + \frac{\lambda\theta}{\phi}\Delta x_{t+2} - \frac{\lambda(1-\theta)}{\phi}\Delta x_{t+3} + \kappa_1 \Delta i_{t+1} + \kappa_2 \Delta i_{t+2}] = 0$$

	π^*	μ	θ	ϕ	λ	κ_1	κ_2	J
				System Estimates				
Forward-Looking Phillips Curve								
60:1 – 79:2	3.82	-63.72	0.85	13.72	9.02	-1.72	0.06	0.05
	(0.26)	(28.15)	(0.04)	(6.90)	(4.46)	(0.70)	(0.48)	
79:3 – 96:4	2.65	-38.78	0.89	8.47	4.60	-0.09	0.15	0.37
	(0.10)	(26.32)	(0.05)	(5.74)	(3.25)	(0.26)	(0.26)	
79:3 – 07:4	2.44	-40.08	0.99	8.71	2.98	-0.11	0.53	0.10
	(0.10)	(19.53)	(0.04)	(4.26)	(1.72)	(0.29)	(0.23)	
Hybrid Phillips Curve								
60:1 – 79:2	5.78	-31.29	0.66	6.72	10.94	0.32	1.86	0.15
	(0.42)	(23.41)	(0.07)	(5.06)	(8.62)	(0.95)	(0.66)	
79:3 – 96:4	2.75	39.09	0.47	-8.51	-22.55	-2.87	1.31	0.20
	(0.40)	(13.65)	(0.05)	(2.96)	(10.98)	(1.12)	(0.87)	
79:3 – 07:3	2.35	-24.05	0.72	5.22	3.00	-0.09	0.56	0.20
	(0.10)	(13.34)	(0.07)	(2.89)	(1.65)	(0.30)	(0.24)	

Notes: Estimation by GMM. Instruments are lags 1 to 4 of: inflation; output gap; wage inflation and (log) wage share. J is the p-value for Hansen's J-statistic for over-identification. Standard errors are in brackets.

4. Conclusions

What have we learned from this paper? There is strong evidence of change in the Fed's target level of inflation towards the end of the 1970s. In the 1960s and 1970s we estimate the target rate of inflation to be between 4 to 5 percent per annum. Since the beginning of the 1980s the target rate of inflation seems to be around 2.5 percent per annum. We find strong statistical support for this decline and the result is consistent with previous findings by Dennis (2006) and Favero and Rovelli (2003). Whether the relative weight that the Fed gives to output stabilisation has also fallen since the end of the 1970s is less certain. Unlike Dennis we do find sizeable (and significant) estimates for λ, leading us to conclude that the Fed does care about output stabilisation (in addition to inflation stabilisation). Furthermore the point estimates of λ generally show a marked decline between the pre-Volcker era and the Volcker-Greenspan-Bernanke era. However the standard errors on the estimates of λ are sufficiently large that we cannot confidently conclude there has been a change in this preference parameter.

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