An Empirical Assessment of Optimal Monetary Policy in the Euro Area*

Xiaoshan Chen †
University of Durham

Tatiana Kirsanova‡
University of Glasgow

Campbell Leith§
University of Glasgow

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Abstract

We estimate a New Keynesian DSGE model for the Euro area under alternative descriptions of monetary policy (discretion, commitment or a simple rule) after allowing for Markov switching in policy-maker preferences and shock volatilities. This reveals that there have been several changes in Euro-area policy making, with a strengthening of the anti-inflation stance in the early years of the ERM, which was then lost around the time of German reunification and only recovered following the turmoil in the ERM in 1992. The ECB does not appear to have been any more conservative as aggregate Euro-area policy was under Bundesbank leadership. The estimates also suggest that the most appropriate description of policy is that of discretion, with no evidence of commitment in the Euro-area. As a result, although both 'good luck' and 'good policy' played a role in the moderation of inflation and output volatility in the Euro-area, the welfare gains would have been substantially higher had policy makers been able to commit. Adopting a flexible price level target would lead to outcomes close to commitment.

Key Words: Bayesian Estimation, Interest Rate Rules, Optimal Monetary Policy, Great Moderation, Commitment, Discretion

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†Address: Durham University Business School, University of Durham, Durham, DH1 3LB; xiaoshan.chen@durham.ac.uk

‡Address: Economics, Adam Smith Business School, Gilbert Scott Building, University of Glasgow, Glasgow G12 8QQ; e-mail tatiana.kirsanova@glasgow.ac.uk

§Address: Economics, Adam Smith Business School, Gilbert Scott Building, University of Glasgow, Glasgow G12 8QQ; e-mail campbell.leith@glasgow.ac.uk

1 Introduction

The 'Great Moderation' in output and inflation volatility has been the subject of much analysis, particularly for the US. Following Sims and Zha (2006) a large literature has emerged which assesses the extent to which this was simply 'good luck' – a favorable shift in shock volatilities – or 'good policy' – a desirable change in monetary policy rule parameters and/or the implicit inflation target. The improvement in policy making is typically associated with the disinflation which followed the appointment of Fed Chairman Paul Volcker in 1979.

Relatively few studies consider the Euro-area economy, despite the fact that policy making within the Euro-area economies has undergone several shifts which could easily be more significant than those observed for the US Fed (see Cabanillas and Ruscher, 2008). Most obviously these policy shifts can be seen in the elimination of national monetary policy making in favor of a single Euro-area monetary authority in the shape of the European Central Bank (ECB) and the associated single currency. However, even prior to the creation of the Euro, Euro-area monetary policy has undergone a number of significant shifts which could impact on the efficacy of that policy. For example, the Bundesbank became the *de facto* leader in monetary policy following the creation of the Exchange Rate Mechanism (ERM) in 1979. Although there were several exchange rate realignments within the ERM in the early years[1], following 1987 the system was relatively stable until the events surrounding 'Black Wednesday' in September 1992. This latter episode has been associated with tensions between the design of policy appropriate for domestic conditions in Germany following reunification in 1990 and the needs of other ERM members (see Buiter et al., 2008). In addition to changes in Germany's status as leader within the ERM, German monetary policy has also evolved, particularly during the early to mid 1980s as the Bundesbank developed its version of 'pragmatic monetarism' (Beyer et al., 2008). More recently the monetary policy leadership role has passed from the Bundesbank to the ECB following the creation of the Euro in 1999. It is therefore interesting to discern whether these events are associated with statistically and economically significant changes in monetary policy making in the Euro-area economies.

In addition, we would also like to assess whether or not switches in European monetary policy appear related to those in the US. Favero and Giavazzi (2008) find that European monetary policy systematically responds to US shocks, while Taylor (2013) argues that, in the years immediately prior to the financial crisis, central banks often moved in lockstep and that this is potentially damaging for global monetary policy. It is therefore interesting to assess the degree of synchroni-

[1]See Ozkan (2003) for a detailed list of these realignments and estimates of their fundamental causes.

sation of policy across the two economies, and, in particular, if a relaxation in the anti-inflation stance of the US Fed following the bursting of the dot-com bubble is correlated with similar moves in Europe.

In order to explore the evolution of Euro-area monetary policy following the formation of the ERM, we estimate a simple DSGE model under alternative descriptions of flexible inflation targeting (Svensson, 2003) and instrument rules, after allowing for switches in both the policy maker's degree of inflation aversion and shock volatilities. This approach follows that in Chen et al. (2013) for the US which finds that the Fed is best described as following a time-consistent discretionary policy with an increase in anti-inflation conservatism associated with the Volcker disinflation. This enhanced conservatism is then temporarily reduced following the stock-market crash of 1987, before being lost again following the bursting of the dot-com bubble without ever being fully regained prior to the financial crisis. In applying this approach to Europe, it is important to note that prior to the introduction of the Euro, European monetary policy was actually being conducted by different central banks so that we are measuring the stance of "average" European monetary policy which will be influenced by both the policies of the Bundesbank and the extent to which other economies were following Germany's lead.

We find that Euro-area policy making is also best described by discretionary policy with several switches in the conservatism of that policy. There is no evidence of the policy maker being able to act with any degree of commitment. The policy switches cast light on the evolution of monetary policy making in the Euro-area, how that differs from the US and the extent to which the ECB can be seen as being a true heir of the Bundesbank. It appears that the Euro-area achieved its equivalent of the Volcker disinflation around two years after the creation of the ERM in 1979 with a marked increase in policy conservatism. However, that conservatism has subsequently been lost on several occasions. Euro-area policy lacked conservatism in the late 1980s, around the time of German reunification and the subsequent turmoil in the ERM on 'Black Wednesday' in September 1992. There has also been a significant relaxation of policy conservatism in the years immediately before the launch of the Euro and for much of the first decade following the Euro's creation. Therefore, policy switches in the US and Europe seem to be associated with different events, and movements in European monetary policy are not merely a reflection of changes in US policy makers' attitudes towards inflation. Moreover, while both policy makers appear to have lost conservatism in the period prior to the financial crisis as argued by Taylor (2013), these reflect quite different policy stances. In the US there is an overshooting of the inflation target, and in Europe an undershooting which would not have been supported by a conservative policy maker in either case.

We then utilise our best-fitting model to undertake various counterfactual analyses of Euro-area policy making. We find that although both 'good luck' and 'good policy' played a role in the moderation of inflation and output volatility in the Euro-area, the welfare gains would have been substantially higher had policy makers been able to commit. In light of the significant potential gains to commitment, we consider a range of delegation schemes and alternative simple target criteria in order to assess how these might bring outcomes closer to those under commitment. A flexible price level target would be most effective in reaping the benefits of commitment.

The plan of the paper is as follows. Section 2 outlines the model. Various descriptions of policy are discussed in Section 3. We then turn to the estimation of the models in Section 4, and in Section 5 we discuss our results before contrasting them with those obtained for the US. Section 6 then undertakes various counterfactual simulation exercises which enable us to explore both the sources and welfare consequences of the 'Great Moderation'. Section 7 considers the ability of various delegation schemes and simple target criteria to achieve some of the sizeable benefits of commitment. We then reach our conclusions in Section 8.

2 The Model

The economy is comprised of households, a monopolistically competitive production sector, and the government. There is a continuum of goods that enter the households' consumption basket. Households form external consumption habits at the level of the consumption basket as a whole, 'superficial' habits. Furthermore, we assume the economy is subject to both price and inflation inertia. Habits and inflation inertia are often employed in empirical applications of the New Keynesian model.[2] While the model extends the benchmark New Keynesian model in this way to ensure data coherence, beyond this it has deliberately been kept relatively simple to ensure the assessment of the empirical validity of alternative descriptions of monetary policy remains transparent. A detailed derivation of the model is given in the online Appendix A.[3]

2.1 Households

The economy is populated by a continuum of households, indexed by k and of measure one. Households derive utility from consumption of a composite good, $C_t^k = \left(\int_0^1 \left(C_{it}^k \right)^{\frac{\eta-1}{\eta}} di \right)^{\frac{\eta}{\eta-1}}$ where η is the elasticity of substitution between the goods in this basket, and suffer disutility

[2] See for example Smets and Wouters (2003), and Christiano et al. (2005).

[3] Hereafter all references to the Appendix refer to the online Appendix.

from hours spent working, N_t^k. Habits are both superficial and external implying that they are formed at the level of the aggregate consumption good, and that households fail to take account of the impact of their consumption decisions on the utility of others. To facilitate data-consistent detrending around a balanced growth path without restricting preferences to be logarithmic in form, we also follow Lubik and Schorfheide (2005) and An and Schorfheide (2007) in assuming that the consumption that enters the utility function is scaled by the economy-wide technology trend, implying that household's consumption norms rise with technology as well as being affected by more familiar habits externalities. Accordingly, households derive utility from the habit-adjusted composite good,

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left[\frac{\left(C_t^k/A_t - \theta C_{t-1}/A_{t-1}\right)^{1-\sigma} \xi_t{}^{-\sigma}}{1-\sigma} - \frac{\left(N_t^k\right)^{1+\varphi} \xi_t{}^{-\sigma}}{1+\varphi} \right], \tag{1}$$

where $C_{t-1} \equiv \int_0^1 C_{t-1}^k dk$ is the cross-sectional average of consumption. Utility is subject to a time-preference or taste-shock, ξ_t. $\mathbb{E}_t$ is the mathematical expectation conditional on information available at time t, β is the discount factor $(0 < \beta < 1)$, and σ and φ are the inverses of the intertemporal elasticities of habit-adjusted consumption and labour supply $(\sigma, \varphi > 0;\ \sigma \neq 1)$.

The process for technology is non-stationary,

$$\begin{aligned} \ln A_t &= \ln \gamma + \ln A_{t-1} + \ln z_t, \\ \ln z_t &= \rho_z \ln z_{t-1} + \varepsilon_t^z. \end{aligned}$$

Households decide the composition of the consumption basket to minimise expenditures, and the demand for individual good i is

$$C_{it}^k = \left(\frac{P_{it}}{P_t}\right)^{-\eta} C_t^k,$$

where P_{it} is the price of good i, and $P_t = \left(\int_0^1 (P_{it})^{1-\eta} di\right)^{1-\eta}$ is the CES aggregate price index associated with the composite good consumed by households. By aggregating across all households, we obtain the overall demand for good i as

$$C_{it} = \int_0^1 C_{it}^k dk = \left(\frac{P_{it}}{P_t}\right)^{-\eta} C_t. \tag{2}$$

Households choose consumption C_t^k, hours worked, N_t^k, and the portfolio allocation, D_{t+1}^k, to maximise expected lifetime utility (1), subject to the budget constraint

$$\int_0^1 P_{it} C_{it}^k di + E_t Q_{t,t+1} D_{t+1}^k = W_t N_t^k (1-\tau_t) + D_t^k + \Phi_t + T_t,$$

and the usual transversality condition. The household's period-t income includes wage income from providing labour services to goods producing firms, $W_t N_t^k$, which is subject to a time-varying tax rate, τ_t , dividends from the monopolistically competitive firms, Φ_t, and payments on the portfolio of assets, D_t^k. Financial markets are complete and $Q_{t,t+1}$ is the one-period stochastic discount factor for nominal payoffs. Lump-sum transfers, T_t, are paid by the government. The tax rate, τ_t, will be used to finance lump-sum transfers, and can be designed to ensure that the long-run equilibrium is efficient in the presence of the habits and monopolistic competition externalities. However, we shall assume that the tax rate fluctuates around this efficient level such that it's effect on inflation can be viewed as an autocorrelated cost-push shock.

In the maximisation problem, households take as given the processes for C_{t-1}, W_t, Φ_t, and T_t, as well as the initial asset position D_{-1}^k. The first order condition for labour is

$$\frac{\left(N_t^k\right)^{\varphi}}{\left(X_t^k\right)^{-\sigma}} = \frac{W_t}{P_t A_t}(1-\tau_t),$$

and taking expectations, the Euler equation for consumption can be written as

$$1 = \beta \mathbb{E}_t \left[\left(\frac{X_{t+1}^k \xi_{t+1}}{X_t^k \xi_t} \right)^{-\sigma} \frac{A_t}{A_{t+1}} \frac{P_t}{P_{t+1}} \right] R_t,$$

where habits-adjusted consumption is defined as $X_t^k \equiv C_t^k / A_t - \theta C_{t-1}/A_{t-1}$ and $R_t^{-1} = \mathbb{E}_t \left[Q_{t,t+1} \right]$ denotes the inverse of the risk-free gross nominal interest rate between periods t and $t+1$.

2.2 Firms

We further assume that intermediate goods producers are subject to the constraints of Calvo (1983) contracts such that, with fixed probability $1-\alpha$ in each period, a firm can reset its price and with probability α the firm retains the price of the previous period, but where, following Yun (1996) that price is indexed to the steady-state rate of inflation. When a firm can set the price, it can either do so in order to maximise the present discounted value of profits, $\mathbb{E}_t \sum_{s=0}^{\infty} \alpha^s Q_{t,t+s} \Phi_{it+s}$, or it can follow a simple rule of thumb as in Galí and Gertler (1999). The constraints facing the forward-looking profit maximisers are the demand for their product given by equation (2) and the constraint that all demand be satisfied at the chosen price. Profits are discounted by the s-step ahead stochastic discount factor $Q_{t,t+s}$ and by the probability of not being able to set prices in future periods. The firm's optimisation problem is

$$\max_{\{P_{it},\, Y_{it}\}} \mathbb{E}_t \sum_{s=0}^{\infty} \alpha^s Q_{t,t+s} \left[\left(P_{it} \pi^s - MC_{t+s} \right) Y_{it+s} \right],$$

subject to the demand curve

$$Y_{it+s} = \left(\frac{P_{it}\pi^s}{P_{t+s}}\right)^{-\eta} Y_{t+s},$$

where the stochastic discount factor is given by

$$Q_{t,t+s} = \beta^s \left(\frac{X_{t+s}\xi_{t+s}}{X_t\xi_t}\right)^{-\sigma} \frac{P_t}{P_{t+s}}.$$

The relative price set by firms able to reset prices optimally in a forward-looking manner, satisfies the following relationship

$$\frac{P_t^f}{P_t} = \frac{\eta}{\eta-1} \frac{\mathbb{E}_t \sum_{s=0}^{\infty} (\alpha\beta)^s \left(X_{t+s}\xi_{t+s}\right)^{-\sigma} mc_{t+s} \left(\frac{P_{t+s}\pi^{-s}}{P_t}\right)^{\eta} \frac{Y_{t+s}}{A_{t+s}}}{\mathbb{E}_t \sum_{s=0}^{\infty} (\alpha\beta)^s \left(X_{t+s}\xi_{t+s}\right)^{-\sigma} \left(\frac{P_{t+s}\pi^{-s}}{P_t}\right)^{\eta-1} \frac{Y_{t+s}}{A_{t+s}}}, \tag{3}$$

where $mc_t = MC_t/P_t$ is the real marginal cost and P_t^f denotes the price set by all firms who are able to reset prices in period t and choose to do so in a profit maximising way.

In addition to the familiar Calvo-type price setters, we also allow for inflation inertia. To do so we allow some firms to follow simple rules of thumb when setting prices. Specifically, when a firm is given the opportunity of posting a new price, we assume that rather than posting the profit-maximising price (3), a proportion of those firms, ζ, follow a simple rule of thumb in resetting that price

$$P_t^b = P_{t-1}^* \pi_{t-1}, \tag{4}$$

such that they update their price in line with last period's rate of inflation rather than steady-state inflation, where P_{t-1}^* denotes an index of the reset prices given by

$$\ln P_{t-1}^* = (1-\zeta) \ln P_{t-1}^f + \zeta P_{t-1}^b.$$

With α of firms keeping last period's price (but indexed to steady-state inflation) and $1-\alpha$ of firms setting a new price, the law of motion of the aggregate price level is

$$(P_t)^{1-\eta} = \alpha \left(P_{t-1}\pi\right)^{1-\eta} + (1-\alpha)\left(P_t^*\right)^{1-\eta}.$$

Denoting the fixed share of price-setters following the rule of thumb (4) by ζ, we can derive a price inflation Phillips curve, as detailed in Leith and Malley (2005). For this we combine the rule of thumb of price setters with the optimal price setting described above, leading to the price Phillips curve

$$\widehat{\pi}_t = \chi_f \beta \mathbb{E}_t \widehat{\pi}_{t+1} + \chi_b \widehat{\pi}_{t-1} + \kappa_c \widehat{mc}_t,$$

where $\widehat{\pi}_t = \ln(P_t) - \ln(P_{t-1}) - \ln(\pi)$ is the deviation of inflation from its steady state value, $\widehat{mc}_t = \ln(W_t/P_t) - \ln A_t - \ln((\eta - 1)/\eta)$, are log-linearised real marginal costs, and the reduced form parameters are defined as $\chi_f \equiv \alpha/\Phi$, $\chi_b \equiv \zeta/\Phi$, $\kappa_c \equiv (1-\alpha)(1-\zeta)(1-\alpha\beta)/\Phi$, with $\Phi \equiv \alpha(1+\beta\zeta) + (1-\alpha)\zeta$.

2.3 The Government

The government collects a distortionary tax on labour income which it rebates to households as a lump-sum transfer. The steady-state value of this distortionary tax will be set at a level which offsets the combined effect of the monopolistic competition distortion and the effects of the habits externality, as in Levine et al. (2008) (see also Appendices A and B). However, shocks to the tax rate described by

$$\ln(1-\tau_t) = \rho^\mu \ln(1-\tau_{t-1}) + (1-\rho^\mu)\ln(1-\tau) - \varepsilon_t^\mu$$

serve as autocorrelated cost-push shocks to the NKPC. There is no government spending per se. The government budget constraint is given by

$$\tau_t W_t N_t = T_t.$$

2.4 The Complete Model

The complete system of non-linear equations describing the equilibrium are given in Appendix A. After log-linearising around the deterministic steady state the model can be summarised by the following set of equations:

$$\sigma \widehat{X}_t + \varphi \widehat{N}_t = \widehat{w}_t - \widehat{\mu}_t, \text{ Labor Supply} \tag{5}$$

$$\widehat{X}_t = \mathbb{E}_t \widehat{X}_{t+1} - \frac{1}{\sigma}\left(\widehat{R}_t - \mathbb{E}_t \widehat{\pi}_{t+1} - \mathbb{E}_t \widehat{z}_{t+1}\right) - \widehat{\xi}_t + \mathbb{E}_t \widehat{\xi}_{t+1}, \text{ Euler Equation} \tag{6}$$

$$\widehat{y}_t = \widehat{N}_t = \widehat{c}_t \text{ Resource Constraint} \tag{7}$$

$$\widehat{X}_t = (1-\theta)^{-1}(\widehat{c}_t - \theta \widehat{c}_{t-1}), \text{ Habits-Adjusted Consumption} \tag{8}$$

$$\widehat{\pi}_t = \chi_f \beta \mathbb{E}_t \widehat{\pi}_{t+1} + \chi_b \widehat{\pi}_{t-1} + \kappa_c \widehat{w}_t, \text{ Hybrid NKPC} \tag{9}$$

$$\widehat{z}_t = \rho^z \widehat{z}_{t-1} + \varepsilon_t^z, \text{ Technology Shock} \tag{10}$$

$$\widehat{\mu}_t = \rho^\mu \widehat{\mu}_{t-1} + \varepsilon_t^\mu, \text{ Cost-Push Shock} \tag{11}$$

$$\widehat{\xi}_t = \rho^\xi \widehat{\xi}_{t-1} + \varepsilon_t^\xi, \text{ Preference Shock} \tag{12}$$

where $\widehat{\mu}_t = \tau\widehat{\tau}_t/(1-\tau)$ represents autocorrelated fluctuations in the labour income tax rate which serves as a cost-push shock. The model is then closed through the addition of one of the descriptions of policy considered in Section 3.

3 Policy

We widen the monetary policy description usually considered in the estimation of DSGE models from a simple Taylor rule to two forms of optimal policy, namely commitment and discretion. We also allow for changes in the degree of inflation aversion implied by each form of policy specification and changes in the volatility of shocks hitting the economy. The best-fitting model is presented in Section 5 and is then used in the counterfactual analysis presented in Section 6.

3.1 Simple Rule Specification

When Euro-area monetary policy is described as a generalised Taylor rule, we specify this rule following An and Schorfheide (2007) as

$$\widehat{R}_t = \rho^R \widehat{R}_{t-1} + (1-\rho^R)[\psi_1 \widehat{\pi}_t + \psi_2(\Delta\widehat{y}_t + \widehat{z}_t)] + \varepsilon_t^R, \tag{13}$$

where the monetary policy maker adjusts interest rates in response to movements in inflation and deviations of output growth from trend.[4] Much of the literature on estimated policy rules finds that there have been significant changes in the conduct of policy over time. Our simple rule-based estimation also takes this into account by allowing for either changes in the policy maker's inflation target or rule parameters. In the former case, following Sims and Zha (2006), we allow the inflation target to follow a two-state Markov-switching process. In the latter case, when the policy changes are described as shifts in rule parameters $(\rho_{s_t}^R, \psi_{1,s_t}, \psi_{2,s_t})$ between two regimes, we adopt the procedure developed by Farmer et al. (2011) to solve the model with Markov-switching in simple rule parameters.

In addition to incorporating monetary policy changes, we also account for the 'good luck' factor that, following Sims and Zha (2006), is modelled as a decrease in the volatility of shocks

[4]Rules of this form have not only been found to be empirically useful, but, when suitably parameterized, can often mimic optimal policy, see, for example, Schmitt-Grohe and Uribe (2007).

hitting the economy. Therefore, we allow for independent regime switching in the variances of the four shocks (i.e. σ_z, σ_μ, σ_ζ and σ_R) between high and low shock volatility regimes.

3.2 Optimal Monetary Policy

Our estimation of optimal policy regimes considers the cases of commitment and discretion, the former allowing the policy maker to make promises concerning their future actions as in a standard Ramsey policy problem and the latter being constrained to be time-consistent. Estimating such optimal policies is clearly dependent on the form of objective function we adopt. An obvious benchmark for such an exercise would be the micro-founded welfare function based on the utility of the households populating our economy.[5] However, such a micro-founded welfare function implies extreme inflation aversion to the extent that the micro-founded weight attached to inflation can be over 100 times that attached to the output terms (see Woodford, 2003, Ch.6). Optimal policies which were based on such a strong anti-inflation objective are likely to be inconsistent with observed inflation volatility. Therefore, for estimation, we assume that the policy maker possesses an objective function of this form, but where the weights on the various terms are freely estimated. We also allow the policy maker to have a desire to smooth their policy instrument, and estimate the extent to which this is the case. This is in common with much of the literature, see Ilbas (2010), Givens (2012) and Le Roux and Kirsanova (2013).

The resulting objective function for estimation is given by

$$L_{est} = \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left\{ \begin{array}{c} \omega_1 \left(\widehat{X}_t + \widehat{\xi}_t \right)^2 + \omega_2 \left(\widehat{y}_t - \frac{\sigma}{\varphi} \widehat{\xi}_t \right)^2 \\ \omega_{\pi,s_t} \left(\widehat{\pi}_t^2 + \frac{\zeta \alpha^{-1}}{(1-\zeta)} \left[\widehat{\pi}_t - \widehat{\pi}_{t-1} \right]^2 \right) + \omega_3 \left(\Delta \widehat{R}_t \right)^2 \end{array} \right\}. \tag{14}$$

This objective function can, following the terminology of Svensson (2003), be interpreted as the central bank's 'general targeting rule'. Conditional on the extent to which they possess a commitment technology, these objectives are then translated into a 'specific targeting rule' obtained by minimising them subject to the description of the economy. Therefore, our approach amounts to a flexible application of Svensson's (2003) notion of targeting rules where the central bank may choose to attach non-microfounded weights to welfare-relevant policy targets.

Under the optimal policy specification we consider potential policy shifts in the form of switches in the weight given to the inflation stabilisation term. Specifically, we allow the weight on inflation, ω_{π,s_t}, to be subject to regime shifting between one and a value lower than one, to capture periods where policy is less conservative. Therefore, we can identify periods where

[5] See Appendix C.

Euro-area policy makers have adopted different attitudes towards inflation over time, for example during the development of ERM and subsequent adoption of the Euro. We adopt the algorithm developed by Svensson and Williams (2007) that solves optimal monetary policies in Markov jump-linear-quadratic systems. The algorithm implies that although policy makers can anticipate any changes in their objectives, they do not attempt to tie the hands of their future selves by altering today's policy plan as part of a strategic game. We consider that this description of evolving policy preferences is in line with the conduct of Euro-area policy, particularly since policy making has been dominated by the Bundesbank and, subsequently, the ECB, both of which enjoy instrument independence.

Finally, as with the model based on simple rules, we allow for independent regime switching in variances of shocks under optimal policy, i.e. σ_z, σ_μ, and σ_ζ.

4 Data, Priors and Identification

4.1 Data

Our empirical analysis uses the aggregate euro area data on output growth (ΔGDP_t), annualised domestic inflation (INF_t) and nominal interest rates (INT_t) from 1979Q1 up to 2008Q3.[6] All data are seasonally adjusted and at quarterly frequencies. Output growth is the log difference of real GDP, multiplied by 100. Inflation is the log difference of GDP deflator, scaled by 400. All data are taken from the AWM database from the ECB (see Fagan et al., 2001).[7]

The data are linked to the recursive equations obtained by solving the model under either a simple rule or optimal policy through a measurement equation specified as:

$$\begin{bmatrix} \Delta GDP_t \\ INF_t \\ INT_t \end{bmatrix} = \begin{bmatrix} \gamma^Q + \Delta\widehat{y}_t + \widehat{z}_t \\ \pi^A + 4\widehat{\pi}_t \\ r^A + \pi^A + 4\gamma^Q + 4\widehat{R}_t \end{bmatrix}, \tag{15}$$

where parameters, γ^Q, π^A and r^A represent the values of output growth, inflation and interest rates when the economy is in its steady state. The average real interest rate, r^A, is linked to the discount factor, β, such that $\beta = \left(1 + r^A/400\right)^{-1}$. For the simple rule with a Markov-switching inflation target, π^A fluctuates between high π^H and low π^L inflation targets. Due to the presence of Markov-switching parameters, the likelihood function is approximated using Kim's

[6] We have also considered the implications of estimating the model over alternative sample sizes, either beginning in the early 1970s or the start of Maastricht Treaty in 1994. This does not affect our conclusions. These results are available upon request.

[7] The specific data series used are the short-term interest rate – STN, Real Gross Domestic Product – YER and GDP Deflator – YED.

(1994) filter, and then combined with the prior distribution to obtain the posterior distribution. A random walk Metropolis-Hastings algorithm is then used to generate 2,500,000 draws from the posterior distribution with the first 1,000,000 draws being discarded and every 50th draw from the remaining draws being saved.[8]

Finally, we compute the log marginal likelihood values for each model to provide a coherent framework within which to compare models with different types of monetary policy. We implement the commonly used modified harmonic mean estimator of Geweke (1999) for this task. We also utilise the approach of Sims et al. (2008) as a robustness check. The latter is designed for models with time-varying parameters, where the posterior density may be non-Gaussian.

4.2 Prior Distributions

The priors are presented in Table 1 and are common across all models. These are set to be broadly consistent with the literature on the estimation of New Keynesian models. For example, the mean of the Calvo parameter, α, is set so that average length of the contract is around one year. Following Smets and Wouters (2003), we choose the normal distribution for inverse of the Frisch labour supply elasticity, φ, and the inverse of the intertemporal elasticity of substitution, σ, with both priors having a mean of 2.5. Habits formation, indexation and the AR(1) parameters of the technology, cost-push, and taste shock processes are assumed to follow a beta distribution with a mean of 0.5 and a standard deviation of 0.15. Standard deviations of shocks are chosen to be highly dispersed inverted Gamma distributions, and the priors for shock variances are set to be symmetric across regimes.

For the model featuring a simple rule subject to Markov-switching in the rule parameters, the priors for these are set in line with Bianchi (2013). The priors of rule parameters on output growth and the interest rate smoothing terms are set to be symmetric across regimes, while asymmetric priors are chosen for the coefficients on inflation. For the simple rule with a Markov-switching inflation target, the priors of inflation targets, π^A and π^H, are set in line with Schorfheide (2005). Finally, for optimal policy, the relative weights (i.e. ω_1, ω_2 and ω_3) in the objective function are assumed to follow beta distributions, and ω_π is allowed to switch between a normalised value of 1 and a value lower than 1, the beta distribution is used for the latter with a mean of 0.5.

[8] Geweke (1992) convergence diagnostics indicate that convergence is achieved. These are available upon request.

4.3 Identification

The identification test of Iskrev (2010) confirms that the fixed parameter versions of our models closed with either a simple rule or optimal policy are identifiable.[9] In addition, the Bayesian learning rate indicator, proposed by Koop et al. (2013), is also applied to our models with Markov-switching in policy and shock variance parameters. Although this indicator does not deliver a 'Yes/No' answer to the question of whether a given parameter is identified as in Iskrev (2010), it indicates the degree of identification. In Appendix D, we present the results obtained by using this indicator on Markov switching parameters. It shows that our models are reasonably well identified.

5 Results

This section presents our estimation results. The posterior means and the 90% confidence intervals are presented in Table 2. Each column corresponds to an alternative policy description, with the columns ordered according to log marginal likelihood values calculated using Geweke (1999) and Sims et al. (2008), respectively. The first column of results in Table 2 is for the best-fitting model, which is a time-consistent discretionary policy, followed by a simple rule with switching in rule parameters, commitment, and then another simple rule with switches in the inflation target. Table 2 also reports the Bayes factor for each alternative model relative to discretion. In this case, using Kass and Raftery (1995) adaptation of Jeffreys (2007) criteria for quantifying the evidence in favor of one model rather than another, the evidence in favor of discretion over simple rules is 'decisive'.[10,11] Therefore, the estimation suggests that there is no significant degree of commitment within Euro-area monetary policy.

We now contrast the results obtained when monetary policy is described by a simple interest rate rule, with those generated when policy is based on either discretion or commitment. We then turn to consider the estimated switches in policy and shock volatility within the Euro-area, contrasting these with comparable estimates for the US, and related studies for Europe.

[9] When considering identification in the context of a fixed parameter model we set $\omega_\pi = 1$ under discretion and commitment policy and assume that the Taylor principle is satisfied when monetary policy is described as a simple rule. Our main results, however, allow for switches in the degree of conservatism and rule parameters.

[10] Following Jeffreys (2007), Kass and Raftery (1995) argue that values of the Bayes Factor associated with two models lying between 0 and 3.2 constitutes evidence which is 'not worth more than a bare mention', between 3.2 and 10 is 'substantial' evidence, between 10 and 100 is 'strong' evidence and above 100 is 'decisive' evidence.

[11] In Appendix E we explore, in more detail, why discretionary policy is better able to fit the data than either simple or more general ad hoc rules despite the fact that optimal policy implies significant cross-equation restrictions.

5.1 Structural Parameter Estimates

If we consider individual parameter estimates obtained under the conventional interest rate rule, then our results are broadly in line with other studies: in the case of the rule with switches in rule parameters we estimate an intertemporal elasticity of substitution, $\sigma = 2.72$; a measure of price stickiness, $\alpha = 0.737$, implying that price contracts typically last for one year; a relatively modest degree of price indexation, $\zeta = 0.065$, a sizeable estimate of the degree of habits, $\theta = 0.757$ and an inverse Frisch labour supply elasticity of $\varphi = 2.478$.[12]

Moving from these estimates obtained under a conventional interest rate rule to the case of optimal policy under discretion, the deep parameter estimates remain largely the same, except that there is a moderate decline in the degree of habits in the model, which falls to $\theta = 0.638$, and an increase in the degree of indexation in price setting to $\zeta = 0.159$. At the same time, where the simple rule relies on preference shocks (both in terms of their standard deviation and persistence) to explain the volatility in the data, the estimates obtained when assuming time-consistent policy significantly raise the estimated size and persistence of cost-push shocks in order to fit the data.[13] These subtle shifts in estimated parameters across discretion and simple rules reflect the nature of the optimal policy problem, and the need for the estimated parameters under optimal policy to generate a meaningful trade-off for the policy maker which can account for the observed volatility of output, inflation and the policy instrument.[14] Accordingly, there is more emphasis on inflation inertia and cost-push shocks under discretionary policy, relative to a simple rule. Moving to commitment policy means that the policy maker is no longer subject to the stabilisation bias, and the estimated variance and persistence of cost-push shocks are higher. Again, this is to help the model achieve a meaningful trade-off for the policy maker and, thereby, explain the observed movements in output and inflation data. Despite this, as we shall see below in Section 6, the commitment policy is simply too effective in stabilising the economy, particularly in terms of inflation, to be a reasonable description of the data.

[12] Similar parameter estimates are obtained for the rule with switches in the inflation target.

[13] When comparing the estimated cost-push shock process with others in the literature it is important to note that our cost-push shock enters the Phillips curve with the reduced form coefficient κ_c, which lies in the range 0.1-0.3 across our estimates.

[14] The benchmark New Keynesian model only contains a meaningful tradeoff between output gap and inflation stabilization in the face of cost-push shocks, see Woodford (2003, Ch.6). Our model also contains a habits externality which means that preference and technology shocks also imply interesting policy trade-offs – see Leith et al. (2012) for a discussion – which are further modified by the presence of inflation inertia.

5.2 Switches in Monetary Policy Conservatism and Shock Volatility

We now turn to consider how the policy making process has changed over time. We find that for all monetary policy specifications considered, we are able to identify a 'less conservative' inflation targeting regime. Under commitment and discretion, this less conservative regime is characterised by lowering the weight on inflation stabilisation from 1 to 0.271 and 0.547, respectively. Under the simple rule, the less conservative regime is captured by either a lower coefficient on excess inflation when rule parameters are allowed to switch, or a higher inflation target.[15] The probability of observing the less conservative regime over the sample period is shown in Figure 1. The adoption of the ERM in 1979 does not appear to have immediately resulted in a switch in the conservatism of policy. However, sometime afterwards policy making does appear to have achieved a higher degree of conservatism. The exact timing of this switch is dependent on the description of the policy embodied in the estimation. For example, under the rule-based policy, a higher degree of conservatism is seen to emerge around the time of the hardening of the ERM in 1987. Conversely, our data-preferred estimates based on discretionary policy-making reveal far more pronounced shifts in policy making throughout the entire sample period. From the mid-1980s Euro-area monetary policy appears to lose conservatism, with the peak loss occurring at the same time as German reunification in early 1990. This is despite the fact that other ERM economies at the time criticised the German authorities for pursuing an aggressively tight monetary policy - in response to the fiscal expansion and wage deals offered in East Germany as part of reunification - which they felt was harming their economies.[16] To the extent that the Euro-area wide data are capturing German monetary leadership in this period, it suggests that perhaps the Bundesbank was not so insensitive to the needs of their ERM/Euro-area partners as is often suggested. Similarly, in the run-up to the creation of the Euro, the estimates suggest that policy gradually lost conservatism. Finally, following the creation of the Euro, the ECB seems to have gone through a sustained loss of conservatism which would not be so apparent under other descriptions of policy.

The probability of being in the high volatility regime is also shown in Figure 1. It shows broadly similar patterns of high volatility regime in the early years of the ERM. There are then additional periods of high shock volatility, but where the exact timing and duration of these episodes varies across the different descriptions of policy. In all cases volatility is reduced following

[15] It is interesting to note that in the estimated less conservative regime the interest rate rule still satisfies the Taylor principle with a coefficient on excess inflation of $\psi_1 = 1.16$.

[16] Buiter et al. (2008) quote tense exchanges between the British Chancellor Norman Lamont and Bundesbank President Helmut Schlesinger as the former repeatedly asked the latter for a commitment to cut German interest rates at a Euromeeting in Bath on 5th and 6th September 1992.

the resolution of tensions in the ERM in August 1993 and does not re-emerge until the financial crisis at the end of the sample period.

We now turn to explore the nature of the policy problem driving the identification of policy regimes under discretion. Under discretion the policy maker is trading off the state of the real economy against inflation, and the fluctuations in conservatism identify shifts in the policy maker's view of that trade-off. In order to explore exactly which aspects of the data are causing the estimation under discretion to label particular periods as being more or less conservative, we construct a welfare relevant output gap. Normally the social planner's allocation would be obtained by maximising utility subject to resource and technology constraints. However, in order to generate insight into our policy maker's decisions we need to consider the estimated objective function. That is we wish to contrast the actual allocation to that which would be chosen by a social planner with preferences which are consistent with those we estimated, and who is subject to the relevant resource and technology constraints. Therefore we minimise the following objective function

$$L = \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left\{ \omega_1 \left(\widehat{X}_t^* + \widehat{\xi}_t \right)^2 + \omega_2 \left(\widehat{y}_t^* - \frac{\sigma}{\varphi} \widehat{\xi}_t \right)^2 \right\}, \tag{16}$$

which is derived from the second order approximation to household utility, after substituting both the resource constraint and production function, $\widehat{y}_t^* = \widehat{N}_t^* = \widehat{c}_t^*$, but where the weights on each term are as estimated above. The definition of habits adjusted consumption is given by

$$\widehat{X}_t^* = (1-\theta)^{-1}(\widehat{y}_t^* - \theta \widehat{y}_{t-1}^*),$$

where the star superscripts denote the fact that we are considering a form of social planner's allocation. The first order condition from this problem can be written as

$$\begin{aligned} \frac{\theta\beta\omega_1}{(1-\theta)^2} \mathbb{E}_t \widehat{y}_{t+1}^* \quad &= \quad \left[\frac{\omega_1}{(1-\theta)^2} + \omega_2 + \frac{\theta^2 \beta \omega_1}{(1-\theta)^2} \right] \widehat{y}_t^* - \frac{\omega_1 \theta}{(1-\theta)^2} \widehat{y}_{t-1}^* \\ &\quad + \left[\frac{\omega_1}{1-\theta} - \frac{\omega_2 \sigma}{\varphi} - \frac{\theta \beta \omega_1 \rho^{\xi}}{1-\theta} \right] \widehat{\xi}_t. \end{aligned}$$

This describes the desired path for output $\widehat{y}_t^*$ that would be chosen by the social planner. Using this as a benchmark we construct the welfare relevant output gap $\widehat{y}_t - \widehat{y}_t^*$ which captures the extent to which the policy maker is unable to achieve this desired level of output due to nominal inertia, the habits externality and time-consistency problems. Effectively, it reflects the welfare trade-offs between inflation and the real economy implied by the estimated objective function and decentralised equilibrium, but captures them in a single measure.

The first row of Figure 2 plots the probability of the policy maker in Europe being less conservative alongside the output and inflation gaps, where the latter are simply the difference between inflation and its steady-state/target value. Here we can see that the initial period of less conservative regime is associated with very high inflation, albeit with a sizeable negative output gap. This then switches in late 1982 to being a more conservative regime as inflation falls, while the negative output gap is maintained. The subsequent gradual loss of conservatism peaking around the time of German reunification is a period where inflation is stuck above target, and although the output gap is negative it is not sufficiently so for the policy to be labelled 'more conservative'. It is only when the output gap widens sufficiently that the policy maker is identified as being conservative around mid-1993. Subsequently this episode of enhanced conservatism is maintained as inflation moves closer to target allowing the output gap to decline. The loss of conservatism immediately prior to the introduction of the Euro and in the early years of the Euro is then quite different as inflation is consistently below the target and is associated with a positive output gap. A more conservative policy maker would have adopted a more expansive monetary policy raising inflation towards target at the price of a larger positive output gap. Therefore, the lack of conservatism in the early years of the ERM is due to a failure to reduce inflation, while during the early years of the Euro it is a failure to raise inflation to target.

Comparison with the US

We can contrast the timing of policy switches identified for the Euro Area with those obtained in Chen et al. (2013) for the US. Figure 2 contrasts the smoothed probabilities of less conservative policy regimes for both the Euro-area and US, in rows 1 and 2, respectively. Interestingly, the German-led disinflation in Europe appears to occur not long after that experienced in the US under Volcker. However, subsequent periods of lost conservatism in Europe appear to be more likely linked to developments in the ERM, including those associated with German reunification, and the desire for stability in the run-up to the formation of the Euro, rather than following the 'Greenspan put' where the US relaxed its policy stance following the stock market crash of 1987 and bursting of the dot-com bubble. However, both policy makers appeared to operate less conservative monetary policies during the relatively benign conditions that preceded the financial crisis. The possibility that these, and other, monetary policy makers were collectively deviating from desirable policies is stressed by Taylor (2013) as a key factor leading to the financial crisis.

We can further investigate the differences between the evolution of policy in the US and Europe by constructing the same measures of inflation and output gaps for the US which are plotted in the second row of Figure 2. This shows that following the appointment of Paul Volcker as US Fed Chairman, the major losses in conservatism were associated with developments in financial markets: the stock market crash of 1987 and the bursting of the dot-com bubble in 2000. In both cases there was an increase in inflation above target, and the output gap was insufficiently negative for the policy maker to be described as being 'more conservative'. This is in contrast to the lost conservatism in the Euro area immediately before and after the introduction of the Euro where policy was identified as being 'less conservative' as a result of failing to raise inflation towards the estimated target, despite the presence of a positive output gap. Therefore, the two policy makers underwent a similar disinflation process in the early 1980s, which was undermined by events surrounding German reunification in Europe and financial market turbulence in 1987 and 2000 in the US, respectively. In contrast, European policy appears less conservative before and after the introduction of the Euro not because of an unwarranted increase in inflation, but because of a failure to raise inflation towards the target as aggressively as a 'more conservative' policy maker would do.

In terms of episodes of high shock volatility across the US and Europe, see Figure 3, we find that in Europe volatility was high until a few years after the 1992 ERM crisis. In contrast, estimates for the US suggest that the reduction in shock volatilities occurred a decade earlier around 1985. There is no evidence in Europe for the episode of high volatility observed in the US following the bursting of the dot-com bubble, possibly reflecting both the location of the major dot-com firms and differences in the structure of financial markets across the US and Europe. Finally, at the end of the sample period, in both the US and Euro-area the global financial crisis is associated with a rise in shock volatility, although, interestingly, the high shock volatilities emerge first in the US before manifesting themselves in Europe.

Comparison with other European Studies

The literature on the Great Moderation in Europe is largely based on reduced-form estimates and contains mixed results on the nature of the Great Moderation in Europe. For example, Cabanillas and Ruscher (2008) specifically explore this issue in the Euro-area and argue that it is due to both good luck, and also substantial improvements in the conduct of monetary policy. However, the exact timing of these changes is not formally estimated, as the authors explore volatility measures over pre-defined sub-samples. Nevertheless, individual studies do echo elements of our results. Rubio-Ramírez et al. (2005) find, using a Markov switching Structural VAR, that the Great Moderation in the Euro-area is largely due to a reduction in shock volatilities which are dated to occur around 1993, similar to our findings. Canova et al. (2008), using a time-varying VAR find that there is limited evidence of structural shifts in the economy, although there have been sizeable changes in the volatilities of structural shocks. Our analysis in Section 6 does not attribute all the Great Moderation in Europe to good luck, although it does find that this is a very significant component.

Trecroci and Vassalli (2010) estimate time-varying interest rate rules for the US, UK, Germany, France and Italy. In the case of Germany they find a strengthening of the anti-inflation policy stance in the early 1980s which is then relaxed around the time of German reunification, consistent with our findings. Finally, Assenmacher-Wesche (2005) estimates monetary policy reaction functions for the US, UK and Germany allowing for switches in the rule parameters and residual variances. Her estimates suggest that Germany is in a low inflation regime between 1983 and 1990, only returning to that regime in 1996. Again, this is not dissimilar to the timing of the more conservative regime observed under our preferred policy description.

Therefore, our analysis appears to pick up features of the data which have been captured across a range of less structural empirical studies, even if none of these individual studies captures all of the nuances of shock volatility and policy switches, unlike our approach.

6 Good Luck versus Good Policy

Our best-fitting model is obtained under discretionary policy with Markov switching in the weight on inflation stabilisation in the policy maker's objectives, as well as switches in the volatility of shocks hitting the economy. This allows us to undertake various counterfactual exercises. For example, using this model we can measure how much 'good luck' or 'good policy' alone can stabilise volatilities in the Euro-area output and inflation.

We compute the unconditional variances of key variables, as well as unconditional welfare under alternative counterfactuals. These values computed under the worst case scenario serve as the benchmark for the 'good luck' versus 'good policy' debate. This benchmark implies being in the high shock volatility regime in conjunction with discretionary policy with the lower level of estimated conservatism, $\omega_\pi = 0.547$. We can then consider the extent to which 'good policy' or 'good luck' alone would be able to stabilise inflation, output and interest rates. Table 3 shows that under discretion an increase in central bank conservatism alone ($\omega_\pi = 1$) would reduce by more than half the volatility in inflation and interest rates implied by the worst case scenario, although with only a negligible impact on output volatility. In contrast, under 'good luck' there is an additional reduction in output volatility. Therefore, it is good luck that achieves bigger gains in terms of welfare.

Turning to the second half of Table 3 we consider the same experiment, but now assume that policy is conducted under commitment. In the absence of 'good luck', the ability to act with commitment can allow central banks to almost completely stabilise inflation volatility, but at the cost of moderate increases in output fluctuations. It is also important to note that outcomes are clearly improved regardless of whether or not the estimated increase in central bank conservatism takes place. This result suggests that the reduction in inflation volatility achieved by being able to act under commitment is such that the issue of conservatism becomes of second-order importance. Therefore, the dimension of 'good policy' we should be concerned with is not the anti-inflation conservatism of the central bank, but rather that they have the tools and credibility to effectively pursue a commitment policy and make time-inconsistent promises which they will keep.

7 Alternative Delegation Schemes and Targeting Criteria

As shown above the gains to commitment are significant for the Euro area. However, the empirical analysis finds that there is no evidence of such commitment. Therefore, in this section we turn to consider whether similar gains can be achieved through either alternative delegation schemes which do not pre-suppose an ability to behave in a time-inconsistent manner or simple target criteria where the latter are a means of communicating the central bank's policy without articulating either a simple instrument rule or the full Ramsey policy.

7.1 Revealed Preferences

In designing our optimal delegation schemes and targeting criteria we need to take a stand on the welfare metric we employ to obtain the appropriate weights within each description of the central bank remit. We assume that in periods where the policy maker was found to be conservative, $\omega_\pi = 1$, society was employing a 'conservative' central banker as in Rogoff (1985) to optimise the outcomes under discretion. This assumption implies that the outcomes of discretionary monetary policy under our conservative regime are as good as they can be under inflation targeting. We would then like to see whether alternative delegation schemes would further improve the outcomes under discretionary monetary policy to bring us closer to the level of welfare achieved under commitment. Therefore to design other optimal delegation schemes, we backward-engineer society's preferences from those estimated for the 'conservative' central banker. This would imply that the latter has a higher degree of inflation conservatism than that of society, whose preferences are

$$L_{rp}=\mathbb{E}_0\sum_{t=0}^{\infty}\beta^t\left\{\begin{array}{c}\omega_1\left(\widehat{X}_t+\widehat{\xi}_t\right)^2+\omega_2\left(\widehat{y}_t-\frac{\sigma}{\varphi}\widehat{\xi}_t\right)^2\\+\omega_{rp}\left(\widehat{\pi}_t^2+\frac{\zeta\alpha^{-1}}{(1-\zeta)}\left[\widehat{\pi}_t-\widehat{\pi}_{t-1}\right]^2\right)+\omega_3\left(\Delta\widehat{R}_t\right)^2\end{array}\right\}, \tag{17}$$

where the 'revealed preference' weight on inflation stabilisation, given our estimated model parameters, is calculated to be $\omega_{rp} = 0.206$. This weight implies that it is optimal for society to delegate monetary policy to a conservative central banker with a weight on inflation of 1 and weights on other elements of welfare, ω_1, ω_2 and ω_3 as estimated. Therefore, to reiterate, we have constructed a 'revealed preference' measure of social welfare which assumes that the anti-inflation conservatism of the central banker whose preferences we estimated was chosen optimally.

7.2 Delegation Schemes

Several delegated targets have been considered in the literature and typically replace the inflation target with an alternative target which introduces some of the inertial behavior that makes commitment so effective. We consider a flexible target for nominal GDP growth (Jensen, 2002) and the price level (Vestin, 2006). Following the financial crisis there have been renewed calls to consider such delegation schemes, particularly as policy has become mired at the zero lower bound (ZLB). For example, Woodford (2012) advocates nominal income targeting as means of generating desirable policy expectations when policy is mired at the ZLB, while Coibion et al. (2012) suggest that rather than raise the inflation target to reduce the risk of hitting the ZLB, a price level target would generate far greater welfare benefits.

Of particular importance in defining the optimal delegation scheme is the extent of any inflation inertia in the model. Vestin (2006) shows that in the absence of such inertia, price level targeting can come close to mimicking the outcomes under commitment.[17] However, as the level of inflation inertia is increased the advantages of all such delegation schemes are reduced, particularly that of price level targeting (see Walsh, 2003). Since the time-consistency problem is driven by economic agents' expectations of the inflationary consequences of policy, it is clear that making the Phillips curve purely backward looking will negate any of the expectational advantages offered by any of these schemes. The source of the shocks hitting the economy is also important in ranking these delegation schemes - nominal income targeting performs relatively well when the shocks hitting the economy create a trade-off between output and inflation stabilisation for the monetary policy maker i.e. cost push shocks. In contrast, technology shocks which typically

[17] In fact, with iid shocks, price level targeting can be shown to be isomorphic to the full commitment solution when the New Keynesian Phillips curve is purely forward-looking.

require a strong monetary policy response, which ensures they do not have any inflationary consequences, would give rise to a sub-optimally weak policy response under nominal income growth targeting. Taken together, this implies that the ranking of these alternative delegation schemes is an empirical question, which our estimated model is well placed to address.

Therefore, in addition to inflation targeting we also consider price level and nominal income targeting schemes. For them we use the revealed preference measure of social welfare (17) to optimally choose the weights on the price level and nominal income targets, while retaining the estimated weights on the real terms, ω_1, ω_2, and ω_3, such that the delegated objectives under price level targeting are the following

$$L_p = \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left\{ \begin{array}{c} \omega_1 \left(\widehat{X}_t + \widehat{\xi}_t\right)^2 + \omega_2 \left(\widehat{y}_t - \frac{\sigma}{\varphi}\widehat{\xi}_t\right)^2 \\ +\omega_p \widehat{p}_t^2 + \omega_3 \left(\Delta \widehat{R}_t\right)^2 \end{array} \right\},$$

where $\widehat{p}_t = \widehat{p}_{t-1} + \widehat{\pi}_t$, while for nominal income growth targeting, the objective function is given by

$$L_{NI} = \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left\{ \begin{array}{c} \omega_1 \left(\widehat{X}_t + \widehat{\xi}_t\right)^2 + \omega_2 \left(\widehat{y}_t - \frac{\sigma}{\varphi}\widehat{\xi}_t\right)^2 \\ +\omega_{NI} \left(\widehat{y}_t - \widehat{y}_{t-1} + z_t + \widehat{\pi}_t\right)^2 + \omega_3 \left(\Delta \widehat{R}_t\right)^2 \end{array} \right\}.$$

where $\widehat{y}_t - \widehat{y}_{t-1} + z_t + \widehat{\pi}_t$ captures the growth in nominal GDP relative to its trend. Using the 'revealed preference' objective function to optimally choose the weights under each delegation scheme implies that the price level target is very flexibly applied (the weight on the optimised price level term is 0.01.), while the weight on nominal income growth is 0.70.[18]

7.3 Targeting Criteria

As an alternative to delegated targets, Woodford (2007) suggests that many central banks communicate their approach to flexible inflation targeting by adopting a simple target criteria of the form

$$\widehat{\pi}_t = -\phi_1 \widehat{y}_t,$$

which captures the bank's desire to gradually eliminate the output gap as inflation converges towards target. We label this 'Target Criterion 1' and it would be consistent with the form of

[18] In contrast to the 'revealed preference' objective function, designing optimal delegation schemes using microfounded social welfare implies a very aggressive response to inflation with inflation and price level targets (with weights of 347 and 370, respectively) effectively resulting in strict inflation targeting. However, nominal income growth targeting cannot mimic strict inflation targeting, which implies that it does not perform as well as the others in minimizing welfare losses and the weight on the nominal income growth target only rises to 4.66.

the optimal discretionary policy undertaken by a conservative central bank in the context of the simple New Keynesian model. Woodford (2007) argues that central banks may be able to improve outcomes, relative to such an approach, by adopting a target criterion which adds an element of price level control

$$\widehat{\pi}_t = -\phi_2 \Delta \widehat{y}_t,$$

which would be the target criterion under commitment in the benchmark New Keynesian model, 'Target Criterion 2'. Summing this criterion over time implies that the output gap will only be eliminated if the sum of inflation deviations are zero, such that the policy maker stabilises not just inflation, but the price level itself, following shocks. We shall explore whether these target criteria offer an alternative means of achieving outcomes close to commitment when embedding them in our estimated model. It should be noted that the form of these criteria is motivated by the optimal policy exercises in the context of the simple New Keynesian model which does not contain the habits, inflation inertia or the desire to smooth the policy instrument which is a feature of our estimated model. The reason for applying them in our richer model is that they may serve as a relatively simple way of communicating the essence of flexible inflation targeting and commitment even although they do not fully capture the detail of Ramsey policy. Optimally choosing the parameters of these target criteria using the revealed preference measure (17) yields target criteria 1 ($\widehat{\pi}_t = 0.1223\widehat{y}_t$) and 2 ($\widehat{\pi}_t = -7.986\Delta\widehat{y}_t$). Interestingly, the inertial elements of our richer model results in optimised Target Criterion 1 placing the opposite sign on the output gap than would be implied in a simpler model.

7.4 Macroeconomic Outcomes and Welfare Ranking

The macroeconomic outcomes under each of these delegation schemes, optimally designed using the revealed preference measure of social welfare are shown in Figure 4. All delegation schemes appear to reduce inflation in the early 1980s. The most effective delegation scheme would have been a price level target, albeit with a very low weight on the price level target implying a great deal of flexibility.

Similarly, we can assess the performance of the two target criteria in stabilising the economy in Figure 5. The two target criteria are very successful in stabilising inflation. However, while such policies are appropriate in the benchmark New Keynesian model for which they are designed, they are far too aggressive in the context of our richer model with inflation inertia, habits, a desire to smooth interest rates and a realistic trade-off between stabilising inflation and the real economy.

This can be seen when comparing Figures 4 and 5. Significantly larger output losses are found when these two targeting criteria are used compared to the delegation schemes. Their failure to improve welfare highlights the dangers of transplanting strong results from simple models to richer environments.

This is confirmed in Table 4 which presents welfare measures and output, inflation and interest rate variances under the high and low volatility regimes. Here nominal income growth targets are clearly the least successful delegated target in terms of inflation volatility, and this is reflected in their welfare performance. Therefore, while inflation targeting performs relatively well, price level targeting comes closest to achieving the welfare levels attained under commitment. Figure 6 illustrates how close the price level targeting delegation scheme can mimic commitment. This also implies that this delegation scheme is not just appropriate for good times, but would have yielded substantial benefits under the high shock volatility regime of the early 1980s too.

8 Conclusions

In this paper we explore the implications of describing policy using two notions of optimal policy, discretion and commitment, when estimating a DSGE model of the Euro-area economy. Our estimates strongly suggest that the data-preferred description of Euro-area policy is that policy makers operate under discretion with several shifts in both the conservatism of monetary policy and the volatility of shocks hitting the economy. These estimates reveal features of the evolution of Euro-area policy making that are not so readily apparent from estimates based on describing policy with a conventional simple rule. Specifically, the Euro-area achieved its equivalent of the Volcker disinflation around two years after the creation of the ERM in 1979 with a marked increase in policy conservatism and associated fall in inflation. However, that conservatism has not been maintained throughout the rest of the sample period. At the time of German reunification and the subsequent turmoil in the ERM around 'Black Wednesday' in September 1992, Euro-area policy lost conservatism. Given that German policy makers were often criticised at the time for conducting an excessively tight monetary policy which reflected their concerns over the inflationary consequences of German re-unification without making concessions to the needs of their ERM partners, this relaxation in policy at the time is striking. There also has been further temporary losses in conservatism a few years before the launch of the Euro and for much of the first decade of the Euro's existence. This latter period of reduced conservatism coincides with a similar episode in the US prior to the financial crisis as stressed in Taylor (2013). However, there is an asymmetry in that the estimations find that while the US was failing to respond aggressively to rises in inflation above target at this time, European policy makers were not acting to raise inflation which had fallen below target. Other switches in policy preferences in Europe do not obviously reflect developments in the US which, post-Volcker, appear to capture responses to volatility in stock markets.

Based on estimates from our best-fit model we re-assess the 'Great Moderation' in the Euro-area and find that both 'good luck' and 'good policy' played a part in reducing inflation volatility. However since increased conservatism implies output losses are the price for this reduction in inflation, the welfare gains from good luck are substantially higher. When we considered what would have happened had policy makers had the ability to commit, then, even without any changes in shock volatilities or anti-inflation conservatism, the welfare gains would be huge and a delegated price level target would have captured many of these gains.

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Figure 1: Markov Switching Probabilities - Policy and Volatility Switches

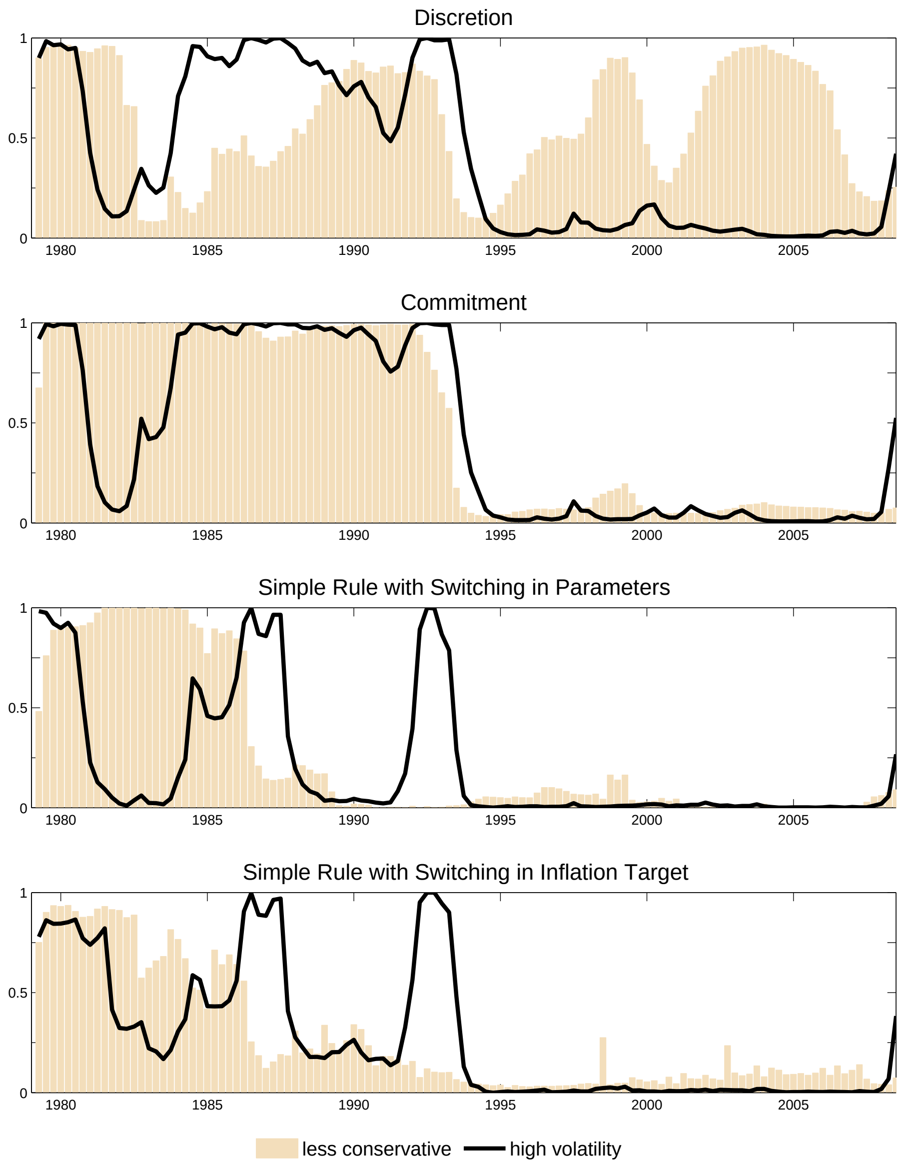
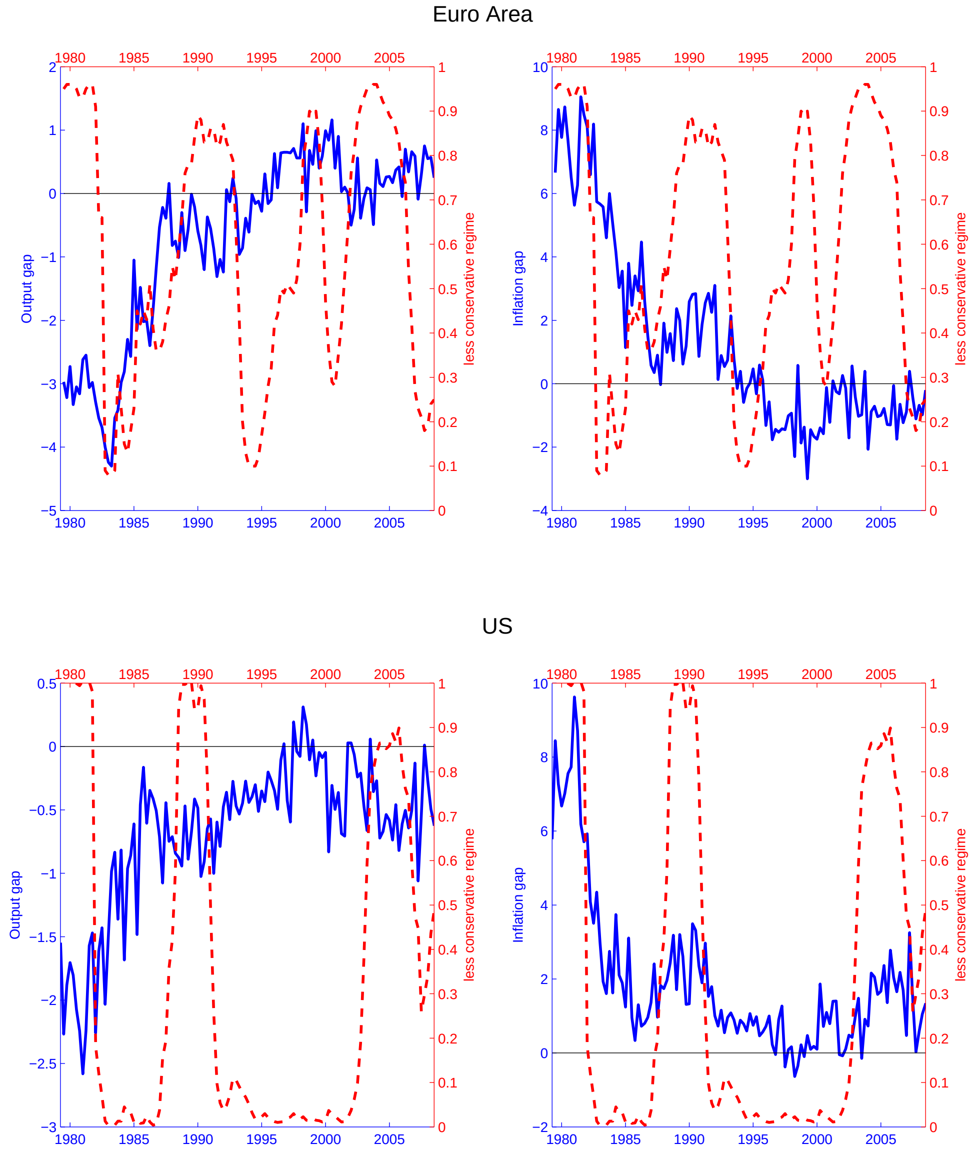
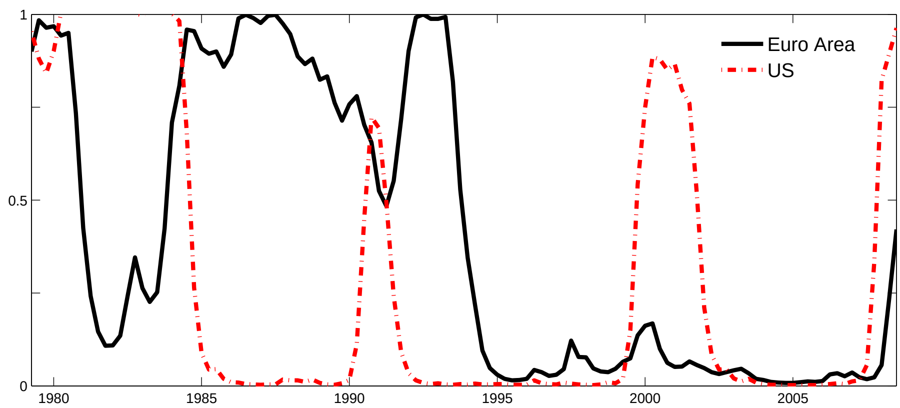


Figure 2: Output and inflation gaps vs. less conservative regime



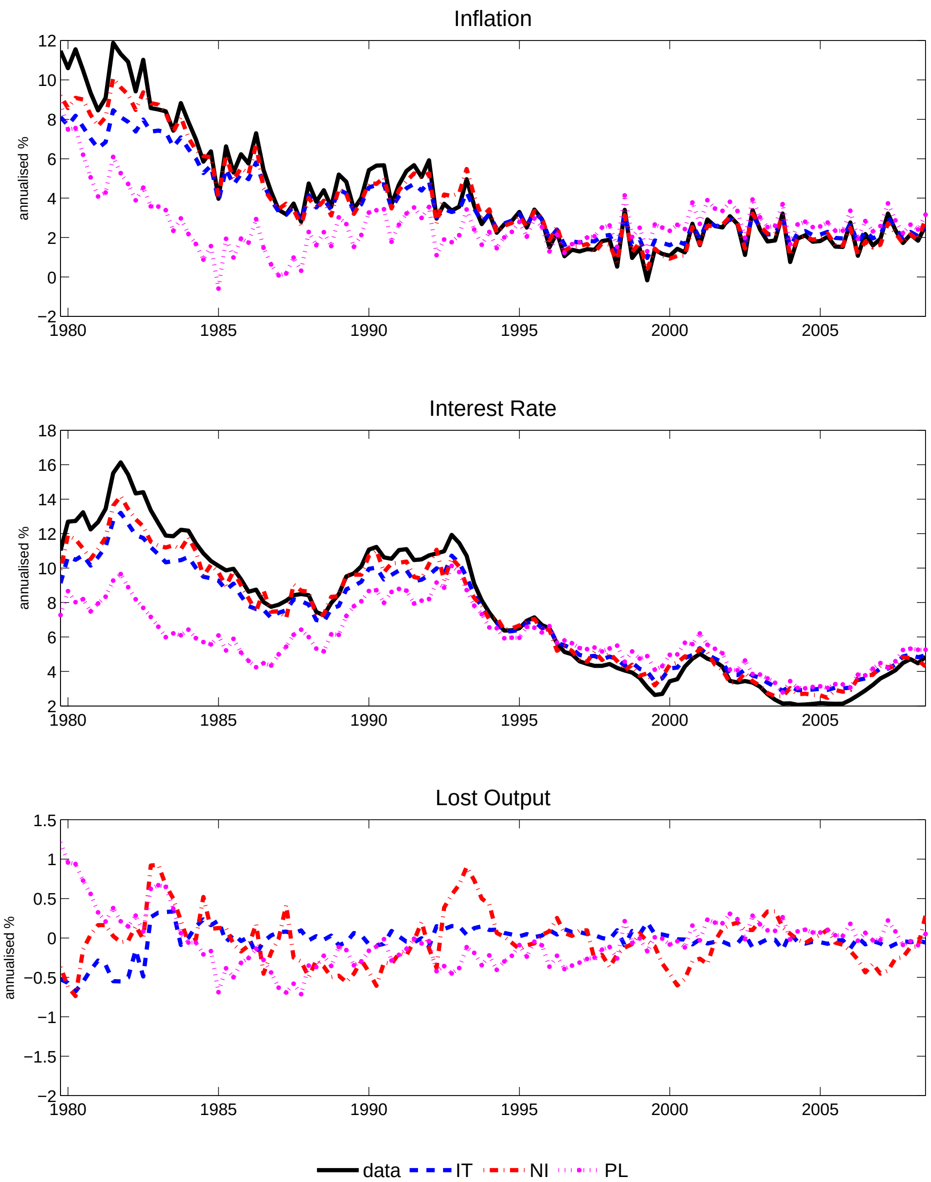
Notes: Solid line denotes output and inflation gaps (left scale) and the dashed line denotes the probability to be in the less conservative regime (right scale).

Figure 3: Low Volatility Regime in the Euro Area and the US



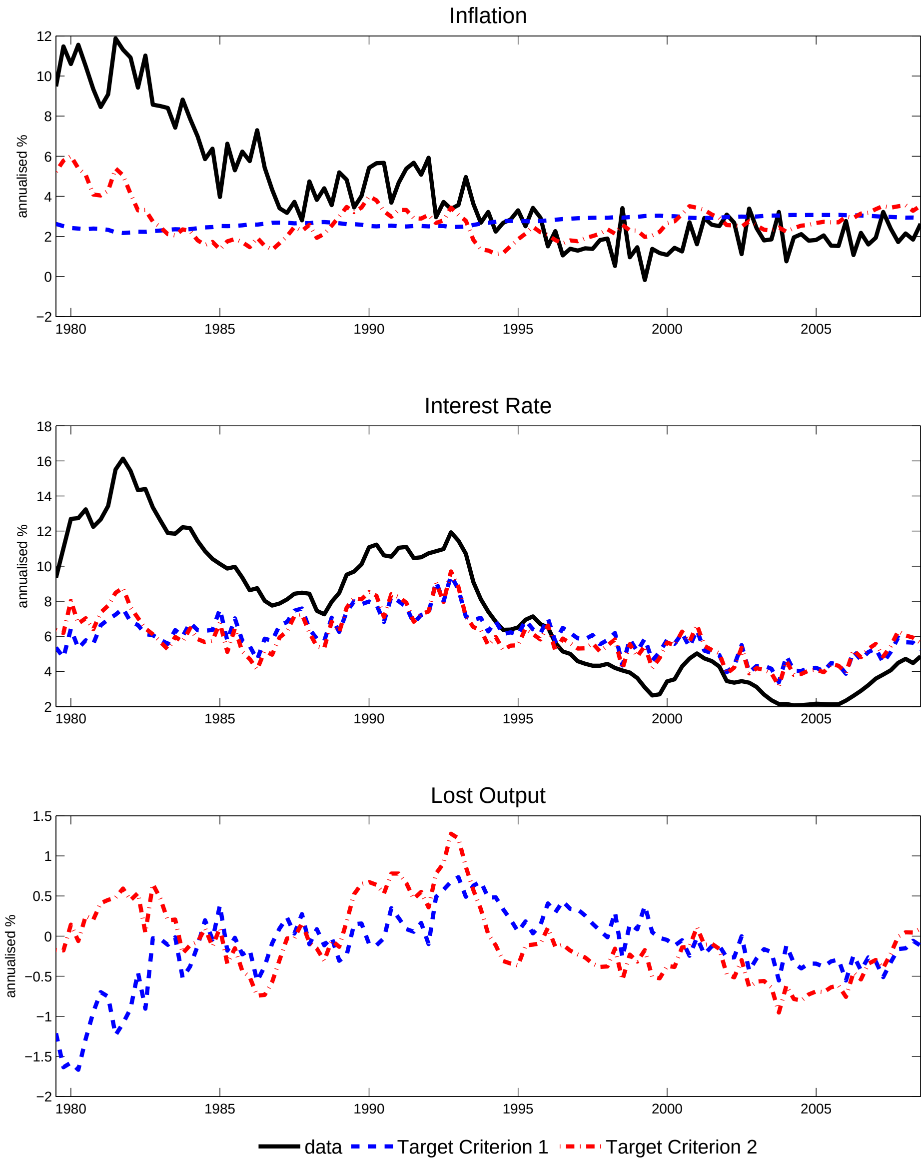
Notes: Solid line denotes output and inflation gaps (left scale) and the dashed line denotes the probability to be in the less conservative regime (right scale).

Figure 4: Counterfactuals: Alternative Delegation Schemes (Revealed Preferences)



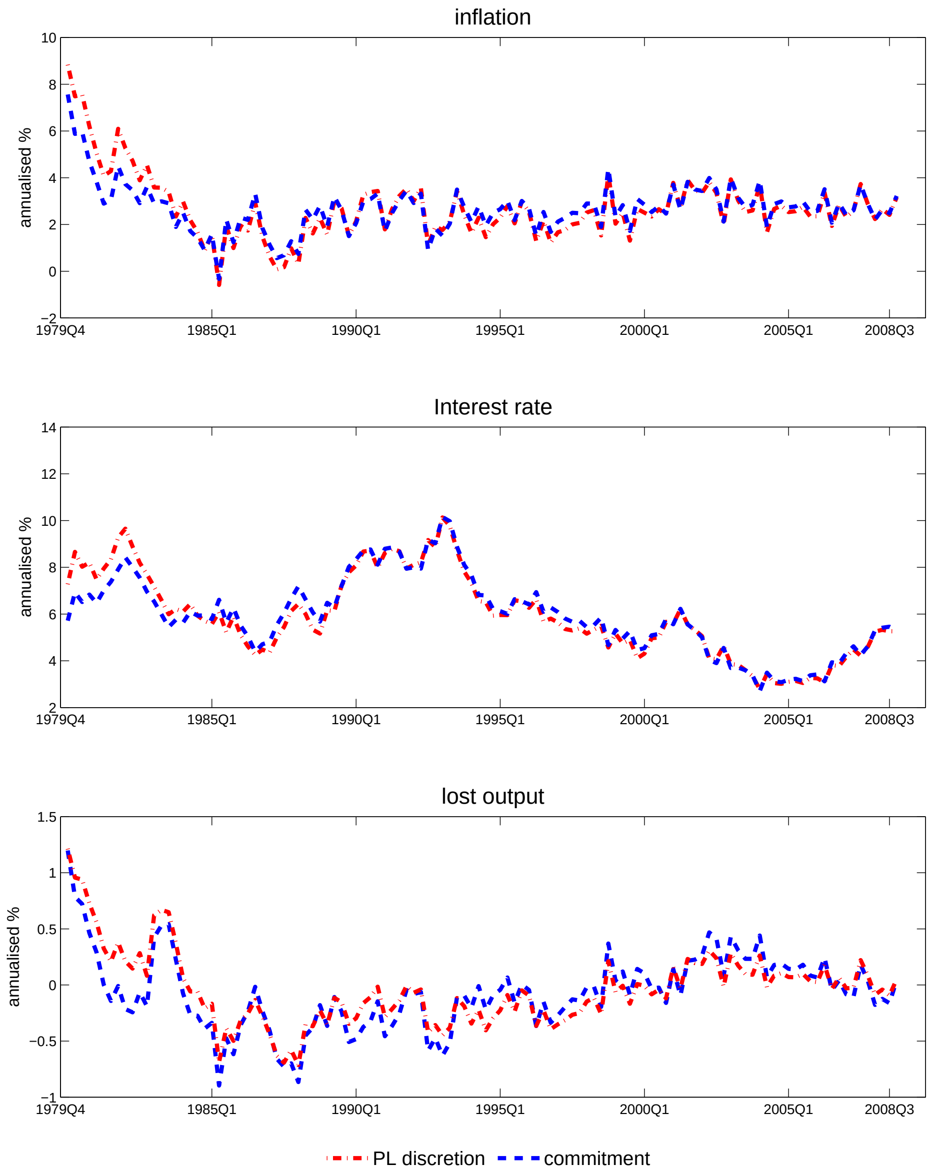
Notes: Lower panel plots the difference between output attained if the policy maker implements the optimally designed delegation schemes using the revealed preference welfare function, and the output from our estimated model under the discretionary policy presented in Table 2.

Figure 5: Counterfactuals: Two Target Criteria (Revealed Preferences)



Notes: Lower panel plots the difference between output attained if the policy maker implements the optimally designed target criteria using the revealed preference welfare function, and the output from the estimated model under discretionary policy presented in Table 2.

Figure 6: Counterfactuals: Commitment versus Discretion (Revealed Preferences)



Notes: Lower panel plots the difference between output attained if the policy maker implements the optimally designed inflation, price level targeting or commitment policy using the revealed preference welfare function, and the output from our estimated model under the discretionary policy presented in Table 2.

Table 1: Distribution of Priors

Parameters		Range	Density	Mean	Std Dev
inv. of intertemp. elas. of subst.	σ	$\mathbb{R}$	Normal	2.50	0.25
Calvo parameter	α	$[0, 1)$	Beta	0.75	0.02
inflation inertia	ζ	$[0, 1)$	Beta	0.50	0.15
habit persistence	θ	$[0, 1)$	Beta	0.50	0.15
inverse of Frisch elasticity	φ	$\mathbb{R}$	Normal	2.50	0.25
AR coeff., taste shock	ρ^{ξ}	$[0, 1)$	Beta	0.50	0.15
AR coeff., cost-push shock	ρ^{μ}	$[0, 1)$	Beta	0.50	0.15
AR coeff., productivity shock	ρ^{z}	$[0, 1)$	Beta	0.50	0.15
steady state interest rate	r^A	$\mathbb{R}^+$	Gamma	3.5	2
inflation target	π^A	$\mathbb{R}^+$	Gamma	3.5	2
steady state growth rate	γ^Q	$\mathbb{R}$	Normal	0.52	1
Markov Switching s.d. of shocks					
taste shocks	$\sigma_{\xi(s=1=2)}$	$\mathbb{R}^+$	Inv. Gamma	0.50	5
cost-push shocks	$\sigma_{\mu(s=1=2)}$	$\mathbb{R}^+$	Inv. Gamma	0.50	5
productivity shocks	$\sigma_{z(s=1=2)}$	$\mathbb{R}^+$	Inv. Gamma	0.50	5
policy shocks	$\sigma_{R(s=1=2)}$	$\mathbb{R}^+$	Inv. Gamma	0.50	5
Markov switching rule parameters					
interest rate smoothing	$\rho^{R}_{(S=1=2)}$	$[0, 1)$	Beta	0.50	0.25
inflation (strong inflation targeting)	$\psi_{1(S=1)}$	$\mathbb{R}^+$	Gamma	1.50	0.50
inflation (weak inflation targeting)	$\psi_{1(S=2)}$	$\mathbb{R}^+$	Gamma	1.0	0.50
output	$\psi_{2(S=1=2)}$	$\mathbb{R}^+$	Gamma	0.50	0.25
Weights on Objectives					
gap term, $\hat{X}_t - \hat{\xi}_t$	ω_1	$[0, 1)$	Beta	0.50	0.15
gap term, $\hat{y}_t - \frac{\sigma}{\varphi}\hat{\xi}_t$	ω_2	$[0, 1)$	Beta	0.50	0.15
change in interest rate, $\Delta\widehat{R}_t$	ω_3	$[0, 1)$	Beta	0.50	0.15
inflation, $\widehat{\pi}_t^2 + \frac{\zeta\alpha^{-1}}{(1-\zeta)}\left[\widehat{\pi}_t - \widehat{\pi}_{t-1}\right]^2$	$\omega_{\pi(S=2)}$	$[0, 1)$	Beta	0.50	0.15
Markov switching in Inflation Target					
inflation target $(S = 1)$	$\pi^{A}_{(S=1)}$	$\mathbb{R}^+$	Gamma	3	2
inflation target $(S = 2)$	$\pi^{A}_{(S=2)}$	$\mathbb{R}^+$	Gamma	6	2
Transition Probabilities					
policy: remaining with strong infl. targeting	p_{11}	$[0, 1)$	Beta	0.90	0.05
policy: remaining with weak infl. targeting	p_{22}	$[0, 1)$	Beta	0.90	0.05
volatility: remaining with low volatility	q_{11}	$[0, 1)$	Beta	0.90	0.05
volatility: remaining with high volatility	q_{22}	$[0, 1)$	Beta	0.90	0.05

Table 2: Estimation Results - Switches in Policy and Volatility

Parameters	Discretion	Rule - Parameters	Commitment	Rule - Target
		Model Parameters		
σ	2.822 [2.466,3.185]	2.726 [2.337,3.113]	2.857 [2.514,3.211]	2.720 [2.332,3.104]
α	0.756 [0.729,0.783]	0.737 [0.704,0.769]	0.779 [0.755,0.803]	0.745 [0.677,0.815]
ζ	0.159 [0.068,0.249]	0.065 [0.021,0.108]	0.148 [0.057,0.234]	0.079 [0.027,0.130]
θ	0.638 [0.459,0.833]	0.757 [0.589,0.929]	0.668 [0.508,0.837]	0.681 [0.450,0.917]
φ	2.242 [1.828,2.646]	2.478 [2.068,2.891]	2.278 [1.884,2.673]	2.461 [2.049,2.880]
		Shock Processes		
ρ^{ξ}	0.850 [0.818,0.882]	0.916 [0.883,0.949]	0.905 [0.874,0.938]	0.930 [0.902,0.959]
ρ^{μ}	0.962 [0.945,0.980]	0.495 [0.243,0.742]	0.986 [0.976,0.996]	0.496 [0.241,0.739]
ρ^{z}	0.266 [0.179,0.353]	0.342 [0.222,0.462]	0.282 [0.194,0.367]	0.376 [0.234,0.516]
$\sigma_{\xi(s=1)}$	0.518 [0.316,0.716]	0.689 [0.405,0.962]	0.425 [0.280,0.566]	0.539 [0.322,0.758]
$\sigma_{\xi(s=2)}$	0.641 [0.408,0.865]	0.739 [0.525,0.943]	0.945 [0.565,1.307]	0.795 [0.446,1.112]
$\sigma_{\mu(s=1)}$	0.275 [0.188,0.356]	0.377 [0.134,0.607]	1.368 [0.644,2.017]	0.3513 [0.1323,0.570]
$\sigma_{\mu(s=2)}$	0.600 [0.411,0.783]	0.642 [0.278,1.018]	1.743 [1.185,2.438]	0.600 [0.283,0.916]
$\sigma_{z(s=1)}$	0.326 [0.273,0.379]	0.343 [0.287,0.397]	0.290 [0.244,0.335]	0.338 [0.277,0.397]
$\sigma_{z(s=2)}$	0.661 [0.529,0.788]	0.802 [0.592,1.006]	0.629 [0.521,0.736]	0.735 [0.535,0.935]
$\sigma_{R(s=1)}$	–	0.121 [0.105,0.138]	–	0.125 [0.105,0.145]
$\sigma_{R(s=2)}$	–	0.314 [0.226,0.398]	–	0.306 [0.214,0.394]
		Data Means		
r^A	1.157 [0.612,1.685]	1.096 [0.653,1.535]	1.123 [0.582,1.651]	0.538 [0.434,0.638]
$\pi^A_{(S=1)}$	2.819 [2.139,3.500]	3.269 [2.759,3.779]	2.390 [1.953,2.788]	2.927 [2.182,3.646]
$\pi^A_{(S=2)}$	–	–	–	3.716 [2.873,4.562]
γ^Q	0.496 [0.409,0.581]	0.536 [0.449,0.623]	0.504 [0.416,0.593]	0.538 [0.434,0.638]

continued on the next page

Table 2: Estimation Results - Switches in Policy and Volatility – continued

Parameters	Discretion	Rule - Parameters	Commitment	Rule - Target
		Policy Parameters		
$\rho^R_{(S=1)}$	–	0.812 [0.773,0.851]	–	0.798 [0.754,0.842]
$\rho^R_{(S=2)}$	–	0.536 [0.395,0.679]	–	–
$\psi_{1(S=1)}$	–	2.025 [1.733,2.312]	–	1.542 [1.228,1.883]
$\psi_{1(S=2)}$	–	1.159 [1.053,1.269]	–	–
$\psi_{2(S=1)}$	–	0.485 [0.399,0.572]	–	0.722 [0.364,1.078]
$\psi_{2(S=2)}$	–	0.281 [0.206,0.353]	–	–
ω_1	0.300 [0.131,0.467]	–	0.482 [0.314,0.648]	–
ω_2	0.712 [0.558,0.868]	–	0.581 [0.400,0.760]	–
ω_3	0.627 [0.426,0.833]	–	0.659 [0.475,0.845]	–
$\omega_{\pi(S=1)}$	1	–	1	–
$\omega_{\pi(S=2)}$	0.547 [0.405,0.690]	–	0.271 [0.130,0.406]	–
		Markov Transition Probabilities		
p_{11}	0.898 [0.839,0.957]	0.958 [0.925,0.990]	0.964 [0.932,0.997]	0.915 [0.848,0.981]
p_{22}	0.933 [0.888,0.983]	0.890 [0.820,0.958]	0.939 [0.894,0.987]	0.828 [0.743,0.918]
q_{11}	0.925 [0.875,0.978]	0.947 [0.915,0.983]	0.941 [0.900,0.984]	0.944 [0.907,0.982]
q_{22}	0.945 [0.905,0.987]	0.868 [0.791,0.946]	0.946 [0.907,0.987]	0.887 [0.810,0.966]
		Log Marginal Data Densities and Bayes Factors		
Geweke (1999)	-367.407 (1.00)	-375.859 ($4.68e{+}3$)	-380.455 ($4.64e{+}5$)	-384.169 ($1.91e{+}7$)
Sims et al. (2008)	-367.556 (1.00)	-376.089 ($5.07e{+}3$)	-381.484 ($1.12e{+}6$)	-384.673 ($2.71e{+}7$)

Notes: For each parameter the posterior distribution is described by mean and 90% confidence interval in square brackets. Bayes Factors for marginal data densities are in parentheses. Computation of the q_L statistic of Sims et al. (2008), which assesses the overlap between the weighting matrix and the posterior density, indicates that the calculated marginal log likelihoods are reliable in every case.

Table 3: Unconditional Variances and Welfare under Alternative Policies and Volatilities

Regime: (conservatism, volatility)	Output	Inflation	Interest Rate	Welfare Cost (est. weights)	Welfare Cost (micro. weights)
			Discretion		
(low, high)	0.258 [0.149,0.405]	1.739 [1.226,2.655]	1.168 [0.700,2.060]	2.599 [1.464,4.856]	0.85% [0.52%,1.32%]
(high, high)	0.255 [0.155,0.412]	0.712 [0.381,1.089]	0.478 [0.317,0.861]	2.494 [1.392,4.740]	0.38% [0.20%,0.61%]
(low, low)	0.139 [0.093,0.216]	1.002 [0.731,1.461]	0.520 [0.326,0.951]	1.370 [0.687,3.117]	0.33% [0.20%,0.50%]
(high, low)	0.125 [0.081,0.197]	0.424 [0.239,0.620]	0.232 [0.163,0.389]	1.358 [0.681,3.083]	0.15% [0.08%,0.26%]
			Commitment		
(low, high)	0.320 [0.199,0.470]	0.137 [0.097,0.198]	0.560 [0.428,0.803]	2.033 [0.980,4.274]	0.15% [0.10%,0.22%]
(high, high)	0.298 [0.187,0.454]	0.064 [0.042,0.093]	0.543 [0.426,0.756]	2.094 [1.026,4..309]	0.10% [0.06%,0.16%]
(low, low)	0.172 [0.118,0.256]	0.099 [0.071,0.144]	0.447 [0.338,0.603]	1.146 [0.551,2.818]	0.09% [0.05%,0.14%]
(high, low)	0.152 [0.100,0.223]	0.048 [0.031,0.067]	0.442 [0.339,0.562]	1.170 [0.568,2.837]	0.06% [0.04%,0.10%]

Notes: The figures in the first three columns measure the unconditional variances of output, inflation and interest rates for estimated parameters in regime (conservatism, volatility). The welfare cost using estimated weights is computed using equation (14). The welfare costs using micro-founded weights is based on the derivation in online Appendix C but is expressed as a percentage of steady-state consumption. For both commitment and discretionary policy we compute social welfare using regimes and regime parameters identified for discretionary policy.

Table 4: Unconditional Variances and Welfare under Alternative Delegation Schemes (Revealed Preferences)

Policy Target	Output	Inflation	Interest Rate	Welfare Cost (revealed weights)
		High Volatility		
Commitment	0.365 [0.218,0.551]	0.382 [0.274,0.561]	0.523 [0.405,0.765]	1.932 [0.928,4.199]
Price Level	0.307 [0.180,0.487]	0.437 [0.310,0.664]	0.484 [0.391,0.676]	1.947 [0.937,4.210]
Inflation	0.255 [0.155,0.412]	0.712 [0.381,1.09]	0.478 [0.317,0.862]	2.137 [1.040,4.355]
Nominal Income	0.252 [0.155,0.404]	0.963 [0.534,1.543]	0.639 [0.406,1.183]	2.196 [1.122,4.398]
Target Criterion1	0.297 [0.193,0.448]	0.004 [0.004,0.007]	0.297 [0.225,0.386]	2.276 [1.175,4.486]
Target Criterion2	0.208 [0.119,0.345]	0.069 [0.051,0.092]	0.322 [0.225,0.386]	2.241 [1.141,4.445]
		Low Volatility		
Commitment	0.221 [0.143,0.335]	0.274 [0.194,0.380]	0.408 [0.308,0.562]	1.100 [0.515,2.776]
Price Level	0.182 [0.113,0.279]	0.296 [0.201,0.439]	0.365 [0.290,0.495]	1.105 [0.517,2.781]
Inflation	0.125 [0.081,0.197]	0.424 [0.239,0.620]	0.232 [0.163,0.389]	1.166 [0.571,2.850]
Nominal Income	0.127 [0.083,0.197]	0.558 [0.338,0.818]	0.298 [0.196,0.548]	1.183 [0.585,2.866]
Target Criterion1	0.133 [0.092,0.209]	0.002 [0.001,0.003]	0.241 [0.182,0.297]	1.291 [0.646,2.928]
Target Criterion2	0.093 [0.058,0.158]	0.031 [0.024,0.041]	0.252 [0.195,0.308]	1.279 [0.635,2.911]

Notes: The table shows the unconditional variances of output, inflation and interest rates under Inflation ($\omega_\pi = 1$), Nominal Income ($\omega_{NI} = 0.7$) and Price Level ($\omega_p = 0.01$) targeting, and target criterion 1 ($\widehat{\pi}_t = 0.1223\widehat{y}_t$) and 2 ($\widehat{\pi}_t = -7.986\Delta\widehat{y}_t$). These have been optimally designed using the revealed preference welfare function (17). The welfare costs in the final column are computed using the revealed preference weights.

Online Appendix to Paper: An Empirical Assessment of Optimal Monetary Policy in the Euro Area

Xiaoshan Chen [*]
University of Durham

Tatiana Kirsanova[†]
University of Glasgow

Campbell Leith[‡]
University of Glasgow

July 13, 2017

[*]Address: Durham University Business School, University of Durham, Durham, DH1 3LB; xiaoshan.chen@durham.ac.uk

[†]Address: Economics, Adam Smith Business School, Gilbert Scott Building, University of Glasgow, Glasgow G12 8QQ; e-mail tatiana.kirsanova@glasgow.ac.uk

[‡]Address: Economics, Adam Smith Business School, Gilbert Scott Building, University of Glasgow, Glasgow G12 8QQ; e-mail campbell.leith@glasgow.ac.uk

A The Complete Model

The complete system of non-linear equations describing the equilibrium are given by

$$
\begin{aligned}
N_t^{\varphi}\left(\frac{X_t}{A_t}\right)^{\sigma} &= \frac{W_t}{A_tP_t}(1-\tau_t) \equiv w_t(1-\tau_t) \\
\left(\frac{X_t}{A_t}\right)^{-\sigma}\xi_t^{-\sigma} &= \beta\mathbb{E}_t\left[\left(\frac{X_{t+1}}{A_{t+1}}\right)^{-\sigma}\frac{A_t}{A_{t+1}}\xi_{t+1}^{-\sigma}R_t\pi_{t+1}^{-1}\right] \\
N_t &= \frac{Y_t}{A_t}\int_0^1\left(\frac{P_t(i)}{P_t}\right)^{-\eta}di \\
X_t &= C_t - \theta C_{t-1} \\
Y_t &= C_t \\
\tau_t W_t N_t &= T_t \\
\frac{P_t^f}{P_t} &= \frac{\eta}{\eta-1}\frac{\mathbb{E}_t\sum_{s=0}^{\infty}(\alpha\beta)^s\left(\frac{X_{t+s}\xi_{t+s}}{A_{t+s}}\right)^{-\sigma}mc_{t+s}\left(\frac{P_{t+s}\pi^{-s}}{P_t}\right)^{\eta}\frac{Y_{t+s}}{A_{t+s}}}{\mathbb{E}_t\sum_{s=0}^{\infty}(\alpha\beta)^s\left(\frac{X_{t+s}\xi_{t+s}}{A_{t+s}}\right)^{-\sigma}\left(\frac{P_{t+s}\pi^{-s}}{P_t}\right)^{\eta-1}\frac{Y_{t+s}}{A_{t+s}}} \\
mc_t &= \frac{W_t}{A_tP_t} \\
P_t^b &= P_{t-1}^*\pi_{t-1} \\
\ln P_{t-1}^* &= (1-\zeta)\ln P_{t-1}^f + \zeta P_{t-1}^b \\
P_t^{1-\eta} &= \alpha\left(\pi P_{t-1}\right)^{1-\eta} + (1-\alpha)\left(P_t^*\right)^{1-\eta} \\
\ln A_t &= \ln\gamma + \ln A_{t-1} + \ln z_t \\
\ln z_t &= \rho_z \ln z_{t-1} + \varepsilon_t^z \\
\ln \mu_t &= \rho_\mu \ln \mu_{t-1} + \varepsilon_t^\mu \\
\ln \xi_t &= \rho_\xi \ln \xi_{t-1} + \varepsilon_t^\xi \\
\ln(1-\tau_t) &= \rho^\mu \ln(1-\tau_{t-1}) + (1-\rho^\mu)\ln(1-\tau) - \varepsilon_t^\mu
\end{aligned}
$$

with an associated equation describing the evolution of price dispersion, $\Delta_t = \int_0^1\left(\frac{P_t(i)}{P_t}\right)^{-\eta}di$, which is not needed to tie down the equilibrium upon log-linearisation. The model is then closed with the addition of a description of monetary policy, which will either be rule based, or derived from various forms of optimal policy discussed in the main text.

In order to render this model stationary we need to scale certain variables by the non-stationary level of technology, A_t such that $k_t = K_t/A_t$ where $K_t = \{Y_t, C_t, W_t/P_t\}$. All other real variables are naturally stationary. Applying this scaling, the steady-state equilibrium conditions reduce to:

$$
\begin{aligned}
N^{\varphi} X^{\sigma} &= w(1-\tau) \\
1 &= \beta R \pi^{-1}/\gamma = \beta r/\gamma \\
y &= N = c \\
X &= c(1-\theta) \\
\frac{\eta}{\eta-1} &= \frac{1}{w}.
\end{aligned}
$$

This system yields

$$
N^{\sigma+\varphi} (1-\theta)^{\sigma} = w(1-\tau). \tag{1}
$$

which can be solved for N. Note that this expression depends on the real wage w, which can be obtained from the steady-state pricing decision of our monopolistically competitive firms. In Appendix B we contrast this with the labour allocation that would be chosen by a social planner in order to fix the steady-state tax rate required to offset the net distortion implied by monopolistic competition and the consumption habits externality.

B The Social Planner's Problem

The subsidy level that ensures an efficient long-run equilibrium is obtained by comparing the steady state solution of the social planner's problem with the steady state obtained in the decentralised equilibrium. The social planner ignores the nominal inertia and all other inefficiencies and chooses real allocations that maximise the representative consumer's utility subject to the aggregate resource constraint, the aggregate production function, and the law of motion for habit-adjusted consumption:

$$
\max_{\{X_t^*, C_t^*, N_t^*\}} \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t u\left(X_t^*, N_t^*, \xi_t, A_t\right)
$$

$$
\begin{aligned}
s.t.\ Y_t^* &= C_t^* \\
Y_t^* &= A_t N_t^* \\
X_t^* &= C_t^*/A_t - \theta C_{t-1}^*/A_{t-1}
\end{aligned}
$$

The optimal choice implies the following relationship between the marginal rate of substitution between labour and habit-adjusted consumption and the intertemporal marginal rate of substitution in habit-adjusted consumption

$$
\left(N_t^*\right)^{\varphi} \left(X_t^*\right)^{\sigma} = (1-\theta\beta)\, \mathbb{E}_t \left(\frac{X_{t+1}^* \xi_{t+1}}{X_t^* \xi_t}\right)^{-\sigma}.
$$

The steady state equivalent of this expression can be written as

$$(N^*)^{\varphi+\sigma}(1-\theta)^{\sigma}=(1-\theta\beta).$$

If we contrast this with the allocation achieved in the steady-state of our decentralised equilibrium given by equation (1), we can see that the two will be identical whenever the tax rate is set optimally to be

$$\tau^*\equiv 1-\frac{\eta}{\eta-1}(1-\theta\beta).$$

Notice that in the absence of habits the optimal tax rate would be negative, such that it is effectively a subsidy which offsets the monopolistic competition distortion. However, for the estimated values of the habits parameter the optimal tax rate is positive as the policy maker wishes to prevent households from overconsuming.

C Derivation of Objective Function

Individual utility in period t is

$$\Gamma_0=\mathbb{E}_0\sum_{t=0}^{\infty}\beta^t\left(\frac{X_t^{1-\sigma}\xi_t^{-\sigma}}{1-\sigma}-\frac{N_t^{1+\varphi}\xi_t^{-\sigma}}{1+\varphi}\right)$$

where $X_t=c_t-\theta c_{t-1}$ is habit-adjusted aggregate consumption after adjusting consumption for the level of productivity, $c_t=C_t/A_t$.

Linearisation up to second order yields

$$\begin{aligned}\Gamma_0 \quad = \quad & \mathbb{E}_0\sum_{t=0}^{\infty}\beta^t\left(\overline{X}^{1-\sigma}\left\{\frac{1-\theta\beta}{1-\theta}\left(\widehat{c}_t+\frac{1}{2}\widehat{c}_t^2\right)-\frac{1}{2}\sigma\widehat{X}_t^2-\sigma\widehat{X}_t\widehat{\xi}_t\right\}\right.\\ & \left.-\overline{N}^{1+\varphi}\left\{\widehat{N}_t+\frac{1}{2}(1+\varphi)\widehat{N}_t^2-\sigma\widehat{N}_t\widehat{\xi}_t\right\}\right)+tip(3).\end{aligned}$$

where where $tip(3)$ includes terms independent of policy as well as terms of third order and higher. For every variable Z_t with steady state value Z we denote $\widehat{Z}_t=\log(Z_t/Z)$.

The second order approximation to the production function yields the exact relationship $\hat{N}_t=\hat{\Delta}_t+\hat{y}_t$, where $y_t=Y_t/A_t$ and $\Delta_t=\int_0^1\left(\frac{P_t(i)}{P_t}\right)^{-\eta}di$. We substitute $\hat{N}_t$ out and follow Eser et al. (2009) in using

$$\sum_{t=0}^{\infty}\beta^t\hat{\Delta}_t=\frac{\alpha}{1-\alpha\beta}\hat{\Delta}_{-1}+\frac{1}{2}\sum_{t=0}^{\infty}\beta^t\frac{\alpha\eta}{(1-\beta\alpha)(1-\alpha)}\left(\widehat{\pi}_t^2+\frac{\zeta\alpha^{-1}}{(1-\zeta)}\left[\widehat{\pi}_t-\widehat{\pi}_{t-1}\right]^2\right)$$

to yield

$$\begin{aligned}\Gamma_0 &= \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left(\overline{X}^{1-\sigma} \left\{ \frac{1-\theta\beta}{1-\theta} \left(\widehat{c}_t + \frac{1}{2}\widehat{c}_t^2 \right) - \frac{1}{2}\sigma \widehat{X}_t^2 - \sigma \widehat{X}_t \widehat{\xi}_t \right\} \right. \\ & \left. -\overline{N}^{1+\varphi} \begin{pmatrix} \widehat{y}_t + \frac{1}{2}\frac{\alpha\eta}{(1-\beta\alpha)(1-\alpha)} \left(\widehat{\pi}_t^2 + \frac{\zeta\alpha^{-1}}{(1-\zeta)} \left[\widehat{\pi}_t - \widehat{\pi}_{t-1} \right]^2 \right) \\ +\frac{1}{2}(1+\varphi)\widehat{y}_t^2 - \sigma \widehat{y}_t \widehat{\xi}_t \end{pmatrix} \right) + tip(3).\end{aligned}$$

The second order approximation to the national income identity yields

$$\widehat{c}_t + \frac{1}{2}\widehat{c}_t^2 = \widehat{y}_t + \frac{1}{2}\widehat{y}_t^2 + tip\,(3)\,.$$

Finally, we use that in the efficient steady-state $\overline{X}^{1-\sigma}(1-\theta\beta) = (1-\theta)\overline{N}^{1+\varphi}$ and collect terms to arrive at

$$\begin{aligned}\Gamma_0 &= -\frac{1}{2}\overline{N}^{1+\varphi}\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left\{ \frac{\sigma(1-\theta)}{1-\theta\beta} \left(\widehat{X}_t + \widehat{\xi}_t \right)^2 + \varphi \left(\widehat{y}_t - \frac{\sigma}{\varphi}\widehat{\xi}_t \right)^2 \right. \\ & \left. + \frac{\alpha\eta}{(1-\beta\alpha)(1-\alpha)} \left(\widehat{\pi}_t^2 + \frac{\zeta\alpha^{-1}}{(1-\zeta)} \left[\widehat{\pi}_t - \widehat{\pi}_{t-1} \right]^2 \right) \right\} + tip\,(3)\,.\end{aligned}$$

After normalising the coefficient on inflation to one, we can write the microfounded objective function as,

$$L_{micro} = \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left\{ \begin{array}{c} \Phi_1 \left(\widehat{X}_t + \widehat{\xi}_t \right)^2 + \Phi_2 \left(\widehat{y}_t - \frac{\sigma}{\varphi}\widehat{\xi}_t \right)^2 \\ + \left(\widehat{\pi}_t^2 + \frac{\zeta\alpha^{-1}}{(1-\zeta)} \left[\widehat{\pi}_t - \widehat{\pi}_{t-1} \right]^2 \right) \end{array} \right\}, \qquad (2)$$

where the weights on the two real terms are functions of model structural parameters, where $\Phi_1 = \frac{\sigma(1-\theta)}{1-\theta\beta}\frac{(1-\beta\alpha)(1-\alpha)}{\alpha\eta}$ and $\Phi_2 = \frac{\varphi(1-\beta\alpha)(1-\alpha)}{\alpha\eta}$.

D A Bayesian Learning Rate Indicator

This section applies the Bayesian learning rate indicator proposed by Koop et al. (2013) to check the degree of parameter identification under discretion, commitment, and the simple rule with Markov switching rule parameters in Table 2. This indicator does not propose a ‘Yes/No’ answer to the question of whether a given parameter is identified. However, it indicates the degree of identification. This indicator is developed on the basis of Bayesian asymptotic theory. As sample size increases, the role of the prior vanishes and the posterior of the parameter asymptotically converges to its true value.

The advantage of this indicator is that it can be easily applied to models with Markov-switching parameters, since it requires only a few additional steps during an ordinary Bayesian estimation. However, applying this indicator requires prior knowledge that a subset of model parameters is known to be identifiable. Therefore, we rely on results obtained using Iskrev (2010) that the fixed parameter versions of our model closed with either a simple rule or optimal policy are identifiable.

In developing this indicator Koop et al. (2013) assume Gaussian priors to obtain analytical solution of posterior precision when the sample period reaches infinity. However, for most DSGE models, the priors are non-Gaussian. Therefore, the exact expression of posterior precision is different from those illustrated in Koop et al. (2013). In applying this indicator to a DSGE model, Caglar et al. (2011) suggest treating the Hessian at the posterior mode as the measure of posterior precision. The technical details of this indicator can be found in Koop et al. (2013). Here, we focus on how this indicator is applied to our Markov switching models.

Let $\theta = [\theta_i, \theta_u]'$ be a vector of model parameters, with the assumption that θ_i is known to be identified, while the identification of θ_u is under question. Prior to applying the Bayesian learning rate indicator, we use Iskrev (2010) to determine how we split the model parameters into θ_i and θ_u. θ_u includes parameters that are associated with Markov switching in policy, shock variances and parameters in the transition matrix. These parameters cannot be incorporated in the Iskrev (2010) test. For both commitment and discretion $\theta_u = [p_{11},\ p_{22},\ q_{11},\ q_{22},\ \sigma_{\xi(s=1,2)},$ $\sigma_{\mu(s=1,2)},\ \sigma_{z(s=1,2)},\ \omega_{\pi(S=2)}]$, while for the simple rule with Markov-switching rule parameters θ_u $= [p_{11},\ p_{22},\ q_{11},\ q_{22},\ \sigma_{\xi(s=1,2)},\ \sigma_{\mu(s=1,2)},\ \sigma_{z(s=1,2)},\ \sigma_{R(s=1,2)},\ \psi_{1(S=1,2)},\ \psi_{2(S=1,2)},\ \rho^R_{(S=1,2)}]$.[1]

To implement this indicator, we simulate samples of artificial data from each models. Models with Markov-switching parameters complicate the data generating processes (DGPs). To simulate data from a Markov-switching model, we need to set the model parameters and the probabilities of each regime. We set model parameters equal to posterior means in Table 2. Unlike when using a fixed parameter model to generate datasets as discussed in Koop et al. (2013) and Caglar et al. (2011), we cannot generate a single large dataset and then take subsets of it to produce smaller samples. This is because probabilities of different sample sizes have to correspond to the estimated transition probabilities ($p_{11},\ p_{22},\ q_{11},\ q_{22}$).

We generate data samples with $T = 100, 1000, 10000$ and 20000. In order to ensure our implementation of this indicator is as comparable as possible across models, we use the same seed for the random number generator for DGPs in each case.

Tables D1, D2 and D3 present the normalised posterior precision of parameters included in θ_u under discretion, commitment and a simple rule. As discussed in Koop et al. (2013), we observe

[1] We set $\omega_{\pi(S=1)} = 1$, therefore $\omega_{\pi(S=1)}$ is not included in θ_u under optimal policy.

that posterior precision need not rise monotonically with T. The posterior precision may, in fact, fall before rising depending on prior type. However, Koop et al. (2013) show that the normalised posterior precision of an unidentified parameter will shrink to zero very quickly as T increases. To make our results robust, we double our sample size from $T = 10000$, the largest sample size used in Koop et al. (2013) to $T = 20000$. It can be seen that none of the normalised posterior precision in θ_u collapse to zero when $T = 20000$. This indicates that our model parameters are reasonably well identified.

Table D1: Posterior precision divided by sample size (Discretion)

Parameters	$n = 100$	$n = 1000$	$n = 10000$	$n = 20000$
Parameters associated with the MS mechanism				
$\omega_{\pi(S=2)}$	5.246	3.280	1.355	0.733
$\sigma_{\xi(s=1)}$	2.022	3.584	2.938	2.778
$\sigma_{\xi(s=2)}$	2.969	0.959	1.628	1.505
$\sigma_{\mu(s=1)}$	7.324	8.812	5.512	7.017
$\sigma_{\mu(s=2)}$	4.447	1.151	1.768	1.815
$\sigma_{z(s=1)}$	7.628	8.525	4.567	8.475
$\sigma_{z(s=2)}$	4.480	1.210	1.704	1.645
p_{11}	8.244	1.692	1.735	1.274
p_{22}	35.245	11.901	3.209	1.804
q_{11}	19.865	2.834	4.836	5.573
q_{22}	12.903	15.956	10.427	11.448

Table D2: Posterior precision divided by sample size (Commitment)

Parameters	$n = 100$	$n = 1000$	$n = 10000$	$n = 20000$
Parameters associated with the MS mechanism				
$\omega_{\pi(S=2)}$	8.262	4.963	4.195	2.766
$\sigma_{\xi(s=1)}$	1.171	1.770	4.881	2.657
$\sigma_{\xi(s=2)}$	3.405	1.184	0.857	0.817
$\sigma_{\mu(s=1)}$	0.154	0.207	0.383	0.318
$\sigma_{\mu(s=2)}$	0.506	0.226	0.251	0.152
$\sigma_{z(s=1)}$	2.969	12.158	11.467	9.317
$\sigma_{z(s=2)}$	4.175	2.602	3.618	2.113
p_{11}	6.023	20.369	20.935	16.786
p_{22}	15.055	14.846	8.503	5.381
q_{11}	10.221	13.311	10.774	8.300
q_{22}	2.451	12.749	14.382	12.000

Table D3: Posterior precision divided by sample size (simple rule)

Parameters	$n = 100$	$n = 1000$	$n = 10000$	$n = 20000$
Parameters associated with the MS mechanism				
$\rho^R_{(S=1)}$	27.191	30.109	29.181	29.731
$\rho^R_{(S=2)}$	2.089	1.469	1.852	3.036
$\psi_{1(S=1)}$	0.538	0.573	0.409	0.504
$\psi_{1(S=2)}$	0.717	1.558	1.764	1.777
$\psi_{2(S=1)}$	2.042	0.605	0.237	0.258
$\psi_{2(S=2)}$	2.636	0.697	0.304	0.327
$\sigma_{R(s=1)}$	48.769	63.814	70.160	67.808
$\sigma_{R(s=2)}$	6.584	6.019	4.348	5.173
$\sigma_{\xi(s=1)}$	1.518	1.967	2.483	2.380
$\sigma_{\xi(s=2)}$	1.007	0.907	0.776	0.703
$\sigma_{\mu(s=1)}$	1.025	0.238	0.015	0.016
$\sigma_{\mu(s=2)}$	0.286	0.041	0.006	0.008
$\sigma_{z(s=1)}$	9.299	8.299	9.649	10.309
$\sigma_{z(s=2)}$	1.035	1.019	0.761	1.047
p_{11}	36.516	21.990	11.710	15.341
p_{22}	5.293	3.395	3.785	4.816
q_{11}	8.116	9.110	11.263	11.229
q_{22}	3.379	2.246	1.762	2.015

E Implicit Interest Rate Rule

This section outlines how, in principle, we can construct an interest rate rule underpinning discretion, and estimates that rule without imposing the cross-equation restrictions implied by discretion.

There are numerous ways of representing the policy rules implied by discretion, which will rarely be unique, even although the equilibrium implied by discretionary policy will be. To consider potential functional forms of an instrument rule we employ the following Lagrangian representation of the policy problem under discretion:

$$\begin{aligned} L \;=\; & \frac{1}{2}\left\{ \begin{array}{c} \omega_1\left((1-\theta)^{-1}(\widehat{y}_t-\theta\widehat{y}_{t-1})+\widehat{\xi}_t\right)^2+\omega_2\left(\widehat{y}_t-\frac{\sigma}{\varphi}\widehat{\xi}_t\right)^2 \\ \omega_{\pi,s_t}\left(\widehat{\pi}_t^2+\frac{\zeta\alpha^{-1}}{(1-\zeta)}\left[\widehat{\pi}_t-\widehat{\pi}_{t-1}\right]^2\right)+\omega_3\left(\Delta\widehat{R}_t\right)^2 \end{array}\right\}+\beta\mathbb{E}_tV_{t+1} \\ & +\lambda_t^1\left[\begin{array}{c} (1-\theta)^{-1}(\widehat{y}_t-\theta\widehat{y}_{t-1})-(1-\theta)^{-1}(\mathbb{E}_t\widehat{y}_{t+1}-\theta\widehat{y}_t) \\ +\frac{1}{\sigma}\left(\widehat{R}_t-\mathbb{E}_t\widehat{\pi}_{t+1}-\mathbb{E}_t\widehat{z}_{t+1}\right)+(1-\rho)\widehat{\xi}_t \end{array}\right] \\ & +\lambda_t^2[\widehat{\pi}_t-\chi_f\beta\mathbb{E}_t\widehat{\pi}_{t+1}-\chi_b\widehat{\pi}_{t-1}-\kappa_c(\sigma(1-\theta)^{-1}(\widehat{y}_t-\theta\widehat{y}_{t-1})+\varphi\widehat{y}_t+\widehat{\mu}_t)], \end{aligned}$$

where, due to the linear-quadratic nature of our policy problem, the expectations variables are a linear function of the states which include $\widehat{\pi}_t$ and $\widehat{y}_t$, while the value function, V_t, will be quadratic in the states. The first order condition for $\widehat{R}_t$ is

$$\omega_3 \Delta \widehat{R}_t - \lambda_t^1 \left[\frac{1}{1-\theta} \frac{\partial \mathbb{E}_t \widehat{y}_{t+1}}{\partial \widehat{R}_t} + \frac{1}{\sigma} \frac{\partial \mathbb{E}_t \widehat{\pi}_{t+1}}{\partial \widehat{R}_t} - \frac{1}{\sigma} \right] - \lambda_t^2 \chi_f \beta \frac{\partial \mathbb{E}_t \widehat{\pi}_{t+1}}{\partial \widehat{R}_t} + \beta \frac{\partial \mathbb{E}_t V_{t+1}}{\partial \widehat{R}_t} = 0.$$

the first order condition for output $\widehat{y}_t$ is given by,

$$\begin{aligned} & \frac{\omega_1}{1-\theta} \left(\frac{1}{1-\theta} \widehat{y}_t - \frac{\theta}{1-\theta} \widehat{y}_{t-1} + \widehat{\xi}_t \right) + \omega_2 \left(\widehat{y}_t - \frac{\sigma}{\varphi} \widehat{\xi}_t \right) \\ & + \lambda_t^1 \left[\frac{1+\theta}{1-\theta} - \frac{1}{1-\theta} \frac{\partial \mathbb{E}_t \widehat{y}_{t+1}}{\partial \widehat{y}_t} - \frac{1}{\sigma} \frac{\partial \mathbb{E}_t \widehat{\pi}_{t+1}}{\partial \widehat{y}_t} \right] \\ & + \lambda_t^2 \left[\widehat{\pi}_t - \chi_f \beta \mathbb{E}_t \widehat{\pi}_{t+1} - \chi_b \widehat{\pi}_{t-1} - \frac{\kappa_c \sigma}{1-\theta} - \kappa_c \varphi \right] + \beta \frac{\partial \mathbb{E}_t V_{t+1}}{\partial \widehat{y}_t} = 0. \end{aligned}$$

and the first order condition for inflation, $\widehat{\pi}_t$, is

$$\begin{aligned} & \omega_{\pi,s_t} \widehat{\pi}_t + \omega_{\pi,s_t} \frac{\zeta \alpha^{-1}}{(1-\zeta)} (\widehat{\pi}_t - \widehat{\pi}_{t-1}) - \lambda_t^1 \left[\frac{1}{1-\theta} \frac{\partial \mathbb{E}_t \widehat{y}_{t+1}}{\partial \widehat{\pi}_t} + \frac{1}{\sigma} \frac{\partial \mathbb{E}_t \widehat{\pi}_{t+1}}{\partial \widehat{\pi}_t} \right] \\ & + \lambda_t^2 \left[1 - \chi_f \beta \frac{\partial \mathbb{E}_t \widehat{\pi}_{t+1}}{\partial \widehat{\pi}_t} \right] + \beta \frac{\partial \mathbb{E}_t V_{t+1}}{\partial \widehat{\pi}_t} = 0. \end{aligned}$$

In principle, we could use the first order conditions for $\widehat{y}_t$ and $\widehat{\pi}_t$ to eliminate the LMs, λ_t^1 and λ_t^2, from the first order condition for $\widehat{R}_t$ to get an implied instrument rule under discretion. However, to write such an instrument rule is complicated and difficult to compare informatively with the estimated simple rules.

Nevertheless, we can see that the implied instrument rule under discretion is a linear function of the following arguments:

$$R_t = f(\widehat{R}_{t-1}, \widehat{\pi}_t, \widehat{\pi}_{t-1}, \widehat{y}_t, \widehat{y}_{t-1}, \widehat{\xi}_t, \widehat{z}_t, \widehat{\mu}_t, \widehat{\xi}_{t-1}, \widehat{z}_{t-1}, \widehat{\mu}_{t-1}).$$

where the rule is a function of the contemporaneous values of all endogenous variables and all states. However, one can manipulate this further, as in Clarida et al. (1999) by substitution of either the IS curve or the NKPC, to show that the interest rate is a function of expected inflation and output, current inflation and output and all states,

$$R_t = f(\widehat{R}_{t-1}, E_t \widehat{\pi}_{t+1}, \widehat{\pi}_t, \widehat{\pi}_{t-1}, E_t \widehat{y}_{t+1}, \widehat{y}_t, \widehat{y}_{t-1}, \widehat{\xi}_t, \widehat{z}_t, \widehat{\mu}_t, \widehat{\xi}_{t-1}, \widehat{z}_{t-1}, \widehat{\mu}_{t-1}).$$

Therefore, we proceed by estimating a very general interest rate rule containing all these terms:

$$\begin{aligned}\widehat{R}_t &= \rho^R_{s_t}\widehat{R}_{t-1} + (1-\rho^R_{s_t})\left(\begin{array}{c}\psi_{1,s_t}\widehat{\pi}_t + \psi_{2,s_t}\widehat{y}_t + \psi_{3,s_t}\widehat{\pi}_{t-1} + \psi_{4,s_t}\widehat{y}_{t-1} \\ +\psi_{5,s_t}E_t\widehat{\pi}_{t+1} + \psi_{6,s_t}E_t\widehat{y}_{t+1}\end{array}\right) \\ &\quad +\psi_7\widehat{z}_t + \psi_8\widehat{\mu}_t + \psi_9\widehat{\xi}_t + \psi_{10}\widehat{z}_{t-1} + \psi_{11}\widehat{\mu}_{t-1} + \psi_{12}\widehat{\xi}_{t-1} + \varepsilon^R_t,\end{aligned}$$

where we allow Markov-switching in parameters of lagged interest rates, expected, current and lagged output and inflation, and we also allow the interest rate to directly respond shocks. Specifically, the priors of $\rho^R_{s_t}$,ψ_{1,s_t} and ψ_{2,s_t} are the same as we reported in Table 1 in the paper, while for the priors of other parameters they are set to follow the normal distribution with wide standard deviations.

We find that the likelihood at the mode of this general rule is superior to discretion, but it is over-parameterised that discretion remains dominant in terms of marginal data density, which is the correct criterion to compare different models within the Bayesian estimation framework. Therefore, generalising the interest rate rule tends to improve the likelihood, but at the cost of increasing model complexity.

Table E1: Model Comparison

Model	likelihood at mode	penalty	MDD
Discretion	-320.023	-50.283	-367.407
Rule - Parameters	-320.761	-56.887	-375.859
Rule - Target	-331.301	-48.834	-384.169
Very General Rule	-303.618	-81.727	-376.615

Note: penalty is calculated as $\frac{d}{2}\ln(2\pi) + \frac{1}{2}\ln(|V|)$, where d is the dimension of the parameter vector and $|V|$ is the determinant of covariance matrix of the posterior.

Table E1 decomposes the marginal data density (which underpins the Bayes factor comparisons of model fit) into the likelihood at the mode and the penalty associated with over-parameterisation. The results suggest that, in terms of likelihood, discretion marginally improves upon a simple rule with switches in parameters, but that the latter is penalised due to the larger number of parameters such that discretion is 'decisively' preferred to the simple rule in terms of Bayes Factors.[2] The rule with switches in the inflation target has fewer parameters and so faces a milder penalty, but the underlying likelihood is less favourable which again accounts for the relative success of discretion.

[2] Discretion requires estimation of the 4 objective function parameters (ω_1, ω_2, ω_3 and ω_π) while the simple rule contains 3 parameters (ρ^R, ψ_1 and ψ_2) which vary across regimes making 6 policy parameters in total.

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