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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 turnoil in the ERM in 1992. The ECB does not appear to have been as conservative as aggregate Euro-area policy was under Bundesbank leadership, and its response to the financial crisis has been muted. 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. We consider a range of delegation schemes as devices to improve upon the discretionary outcome, and conclude that price level targeting would have achieved welfare levels close to those attained under commitment, even after accounting for the existence of the Zero Lower Bound on nominal interest rates.

Key Words: Bayesian Estimation, Interest Rate Rules, Optimal Monetary Policy, Great Moderation, Commitment, Discretion, Zero Lower Bound, Financial Crisis, Great Recession

JEL Reference Numbers: E58, E32, C11, C51, C52, C54

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1 Introduction

The 'Great Moderation' in output and inflation volatility has been the subject of much analysis, particularly for the US, where 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 Volcker disinflation which tends to be dated as occurring in 1979.[1]

Much of the literature surrounding the 'good policy' versus 'good luck' debate is concerned with the US economy and shifts in US Fed policy, while relatively few studies consider the Euro-area economy. However, 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 the discussion in Cabanillas and Ruscher, 2008). Most obviously this 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[2], 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 within Germany following German reunification in 1990 and the needs of other ERM members (see Buiter, Corsetti, and Pesenti, 2008). In addition to changes in its 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, Gaspar, Gerberding, and Issing, 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 this paper, we shall explore the changes in Euro-area policy making by estimating a simple DSGE model under the alternative descriptions of optimal and rule-based policy, and allowing for switches in both policy maker preferences (or rule parameters when policy is described by a

[1] See Chen, Kirsanova, and Leith (2013b) for a discussion of the various strands of this literature.

[2] See Ozkan, 2003, for a detailed list of these realignments and estimates of their fundamental causes.

simple rule) and shock volatilities. We find that Euro-area policy making is best described by optimal discretionary policy with several switches in the conservatism of that policy, as well as switches in the volatility of shocks. These switches cast light on the evolution of monetary policy making in the Euro-area, and the extent to which the ECB can be seen as being a true heir of the Bundesbank.

We then utilize our best-fitting model to undertake various counterfactual analyses of Euro-area policy making. We begin by assessing the relative contributions of 'good luck' and 'good policy' to the 'Great Moderation' in the Euro-area. More importantly, we assess the gains to commitment, and find these to be substantial relative to either good luck or increased conservatism. Therefore, we extend the discussion of 'good policy' as it relates to the weight attached to inflation stabilization in the policy maker's objective function, to consider alternative delegation schemes (price level targets, speed limit policies and nominal income growth targets) as a means of bringing policy outcomes closer to those observed under commitment. This analysis suggests that (flexible) price level targeting yields the greatest benefits under both high and low shock volatilities.

Finally we consider the impact of the recent financial crisis and the conduct of the ECB during that crisis. We identify the shocks and switches in regimes which describe the evolution of the crisis and find that monetary policy in the Euro area became 'less conservative' in the sense that the ECB did not respond aggressively to the undershooting of the inflation target during this period, particularly during the second wave of the crisis in 2012/13. Moreover, had the ECB retained its concern for the inflation target or had been following a flexible price level target then it would have safely avoided reaching the Zero Lower Bound (ZLB). However, during the crisis itself, nominal income targeting would, briefly, have been welfare improving by reducing the drop in output that was observed.

Related Papers for the Euro Area

A limited number of studies focus on the Euro-area including Canova, Gambetti, and Pappa (2008) who use a time-varying VAR estimated for the US, UK and Euro-area. They find that there is limited evidence of structural shifts in the economy, although there have been sizeable changes in the volatilities of structural shocks. Cecioni and Neri (2011) use both a VAR and a DSGE model to explore changes in the Euro-area Monetary Policy Transmission Mechanism (MPTM). Using the VAR they find little change in the MPTM, but by estimating a DSGE model over two sub-samples (before and after the adoption of the Euro) they find that a combination of lower price stickiness and a greater inflation stabilization, effectively offset each other in generating the apparent stability in the impact of Euro-area monetary policy. Similarly, O'Reilly and Whelan (2005) use reduced form regressions to argue there has been no major change in inflation persistence in the Euro-area. Cabanillas and Ruscher (2008), specifically address the question of the Great Moderation in the Euro-area, and argue that it is due to a combination of good luck (reduced shock volatility), but also substantial improvements in the conduct of monetary policy, as well as, to a lesser extent, improved functioning of automatic fiscal stabilizers. Rubio-Ramírez, Waggoner, and Zha (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.

Other studies, starting with Clarida, Galí, and Gertler (1998), consider German monetary policy in isolation but are also of interest given the Bundesbank's leadership role within the ERM. Clarida et al. (1998) find that the Bundesbank was not following a pure monetary growth target, but was concerned with real and inflationary developments. Moreover, they also find that other major economies such as the UK, France and Italy were heavily influenced by German monetary policy even before the hardening of the ERM. 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. Finally, Assenmacher-Wesche (2005) estimates monetary policy reaction functions for the US, UK and Germany allowing for switches in the rule parameters and/or residual variances. Her estimates suggest that Germany entered a low inflation regime between 1983 and 1990, only returning to that regime in 1996. To our knowledge there are no estimates of a Euro-area model which consider alternative descriptions of monetary policy other than a simple rule, in conjunction with the shifts in policy and shock volatilities.

The plan of the paper is as follows. Section 2 outlines our model, and the policy-maker's preferences. Our various descriptions of policy are discussed in Section 3. We then turn to consider the issues relating to the estimation of our model in Section 4. Section 5 then undertakes various counterfactual simulation exercises which enable us to explore both the sources and welfare consequences of the 'Great Moderation', and the ability of alternative delegation schemes to achieve welfare levels approaching those under commitment. The policy response to the recent financial crisis and the robustness of our delegation schemes to the existence of the ZLB is considered in Section 6. The robustness of our results is discussed in Section 7. We then reach our conclusions in Section 8.

2 The Model

The economy is standard and 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. Adding habits and inflation inertia are often employed in empirical applications of the New Keynesian model.[3] Detailed derivation of the model is given in the Technical Appendix.[4]

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 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 work $(\sigma, \varphi > 0;\ \sigma \neq 1)$.

[3] See for example Smets and Wouters (2003), Christiano, Eichenbaum, and Evans (2005), Leith and Malley (2005) and Chen et al. (2013b).

[4] Available from the authors or online.

The process for technology is non-stationary,

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

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

$$C_{it}^k = \left(\frac{P_{it}}{P_t}\right)^{-\eta} C_t^k = \left(\frac{P_{it}}{P_t}\right)^{-\eta} \left(X_t^k + \theta C_{t-1}\right).$$

By aggregating across all households, we obtain the overall demand for good i as

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

Remainder of the Household's Problem Households choose the habit-adjusted consumption aggregate, $X_t^k = C_t^k/A_t - \theta C_{t-1}/A_{t-1}$, hours worked, N_t^k, and the portfolio allocation, D_{t+1}^k, to maximize 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 labor 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 is responsible for generating an autocorrelated cost-push shock.

In the maximization 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 conditions for labor 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 $R_t^{-1} = \mathbb{E}_t [Q_{t,t+1}]$ 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 maximize 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, or Leith and Malley, 2005). The constraints facing the forward looking profit maximizers are the demand for their own good (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 system of demands

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

where the stochastic discount factor is given by

$$Q_{t,t+s} = \beta^s \left(\frac{X_{t+1} \xi_{t+1}}{X_t \xi_t} \right)^{-\sigma} \frac{P_t}{P_{t+s}}$$

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 maximizing 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-maximizing 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 there 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

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

P_t represents the price level at time t. 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 this price index 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-linearized real marginal costs, and the reduced form parameter convolutions 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 labor 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, McAdam, and Pearlman (2008) (see also the Technical 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-linearizing around the deterministic steady state the model can be summarized by the following set of equations:

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

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

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

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

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

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

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

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

where $\widehat{\mu}_t = \tau \widehat{\tau}_t / (1-\tau)$ represents autocorrelated fluctuations in the labor 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.

2.5 Objective Function

Since we wish to assess the empirical implications of assuming policy is described by various forms of optimal policy rather than a simple rule we need to define the policy maker's objectives. Technical Appendix C derives an objective function based on the utility of the households populating the economy as

$$L = -\frac{1}{2}\overline{N}^{1+\varphi}\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left\{ \begin{array}{c} \frac{\sigma(1-\theta)}{1-\theta\beta}\left(\widehat{X}_t + \widehat{\xi}_t\right)^2 + \varphi\left(\widehat{y}_t - \frac{\sigma}{\varphi}\widehat{\xi}_t\right)^2 \\ +\frac{\alpha\eta}{(1-\beta\alpha)(1-\alpha)}\left(\widehat{\pi}_t^2 + \frac{\zeta\alpha^{-1}}{(1-\zeta)}\left[\widehat{\pi}_t - \widehat{\pi}_{t-1}\right]^2\right) \end{array} \right\} + tip + O[2] \tag{13}$$

which shall underpin the optimal policy estimation and analysis. Therefore, rather than adopt an ad hoc objective function defined in terms of output and inflation, we have an objective function which is fully consistent with the underlying model and which accounts for habits externalities, and both price level and inflation inertia. As a result the objective function contains dynamics in output and inflation.

When adopting one of the forms of optimal policy as our description of monetary policy within the estimation, we shall assume that the policy maker possesses an objective function of this form, but where the weights on the various terms are freely estimated. This can capture the fact that the conservatism of the central bank may differ from that of the representative household. We also, in common with much of the literature (see, for example, Dennis (2004), Adolfson, Laseen, Linde, and Svensson (2011), Ilbas (2010) , Debertoli and Nunes (2010), Givens (2012) and Le Roux and Kirsanova (2013)) allow the policy maker to have a desire to smooth their policy instrument, and estimate the extent to which this is the case.[5] Below, we shall contrast these estimated objective function weights with those implied by the strict application of microfounded weights, given the estimated structural parameters of the model, in addition to assessing how the households' evaluation of the welfare implications of policy differs from that of the policy maker. Finally, we shall also apply the arguments of Rogoff (1985) in deriving an estimate of society's welfare function given the estimated preferences of the policy maker. In other words we shall ask, what must society's preferences have been for them to appoint a 'conservative' central banker of the type we observe - we label these 'revealed preferences'. We shall then consider these three metrics of social welfare - micro-founded preferences, estimated preferences and 'revealed preferences' - in designing optimal delegation schemes for the Euro-area economy.

3 Policy

We consider three basic forms of policy, a simple rule and optimal policy under commitment and discretion, to close our model when undertaking the estimation. We shall also allow for Markov switching in rule parameters and the inflation target, as well as the relative weight given to inflation stabilization under optimal policy.[6]

[5] We also consider the implications of not including this term, see Section 5.2 and Appendix A.

[6] Chen et al. (2013b) also consider an intermediate case of quasi-commitment where the policy maker randomly reneges on their commitment plans, prior to formulating a new plan - see Appendix A. Such a description of policy nests the polar cases of commitment and discretion. However, such a formulation is never preferred by the data.

3.1 Simple Rule Specification

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

$$R_t = \rho^R R_{t-1} + (1-\rho^R)[\psi_1 \widehat{\pi}_t + \psi_2(\Delta \widehat{y}_t + \widehat{z}_t)] + \varepsilon_t^R \tag{14}$$

where the monetary policy maker adjusts interest rates in response to movements in inflation and deviations of output growth from trend.[7] We capture potential policy changes in the context of simple rules in two ways, by allowing either for changes in the policy maker's inflation target or rule parameters. In the former case the measure of excess inflation in the Taylor rule, $\widehat{\pi}_t$, requires we remove the inflation target from the data. Following Schorfheide (2005), we allow that inflation target to follow a two-state Markov-switching process. In addition, when the policy changes are described as shifts in rule parameters (ρ^R, ψ_1, ψ_2) between two regimes, we adopt the procedure developed by Farmer, Waggoner, and Zha (2008) 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 normally modelled as a decrease in the volatility of shocks hitting the economy. Therefore, we allow for independent regime switching in the variances of 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

As for optimal monetary policy, our estimation is based on optimal policy derived under commitment and discretion. 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. 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 than 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 (we explore this issue further in Section 5.2). Therefore, for estimation, we adopt a form of the objective function which is consistent with the representative agents' utility, but allow for a possible desire for interest rate smoothing on the part of the central bank as well as the weights within the

[7] It should be noted that 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).

objective function in (13) to be freely estimated. The resulting objective function is given by

$$\Gamma = -\overline{N}^{1+\varphi}\frac{1}{2}\mathbb{E}_0\sum_{t=0}^{\infty}\beta^t \left\{ \begin{array}{c} \omega_1\left(\widehat{X}_t+\widehat{\xi}_t\right)^2+\omega_2\left(\widehat{y}_t-\frac{\sigma}{\varphi}\widehat{\xi}_t\right)^2 \\ +\omega_3\left(\Delta\widehat{R}_t\right)^2+\omega_\pi\left(\widehat{\pi}_t^2+\frac{\zeta\alpha^{-1}}{(1-\zeta)}\left[\widehat{\pi}_t-\widehat{\pi}_{t-1}\right]^2\right) \end{array} \right\}, \tag{15}$$

Since the estimated welfare function has a form which encompasses the micro-founded objective function, this facilitates an exploration of the policy implications of the estimated weights differing from the micro-founded weights, as well as the central banker's preferences differing from those of society, more generally.

Given that much of the literature on estimated policy rules finds that there have been significant changes in the conduct of policy over time, we focus on identifying potential changes in the Euro-area monetary policy objective on inflation targeting. We adopt the algorithm developed by Svensson and Williams (2007) that solves optimal monetary policies in Markov jump-linear-quadratic systems. This algorithm incorporates structural changes in both the model (5) - (12) and weights in the objective function (15).[8] Specifically, we allow the weight on inflation, ω_π, to be subject to regime shifting between one and a value lower than one. By doing so, we can identify whether there are periods where Euro-area policy makers have adopted different attitudes towards inflation over time, particularly given developments in the ERM and subsequent adoption of the Euro. Svensson and Williams (2007)'s 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, instead they set today's policy cooperatively with their future selves. We consider that this algorithm is in line with the conduct of Euro-area policy as there may be some evolution in the consensus surrounding the objectives of monetary policy, particularly since policy making has been dominated by the Bundesbank and, subsequently, the ECB, both of which enjoy instrument independence. However, in other policy making environments, where interest rate decisions are made by partisan politicians who may alternate in office, this would be less defensible and the approach of Debertoli and Nunes (2010) would be applicable.

Finally, as with the model with the simple rules, we allow for independent regime switching in variances of shocks under optimal policy, i.e. σ_z, σ_μ, and σ_ζ. This is to account for the 'good luck' factor and to obtain more reliable parameter estimates by avoiding the biases associated with the heteroscedastic errors that would emerge if such shifts in shock volatility were not accounted for.

[8] The algorithm used to solve the Markov-jump linear quadratic system is described in Svensson and Williams (2007). We focus on the scenario where no learning occurs and the central bank and private agents can observe the different monetary policy regimes.

Therefore, to summarize, we consider three basic forms of policy: simple rules, commitment and discretion. We also allow for Markov switches in the variances of the shock processes and, in the case of rules, switches in the inflation target or rule parameters, as well as changes in the degree of central bank conservatism under both optimal discretionary and commitment policies. We use three data series in estimation: output, inflation and interest rates. There are three shock processes for technology, preferences and cost-push shocks.

The next section will discuss our estimation strategy. However, before doing so it is important to note that all model parameters are identifiable. To demonstrate this, we used the Iskrev (2010) local identification test for our models based on a simple rule as well as optimal policy under both commitment and discretion.

4 Estimation

Our empirical analysis uses the aggregate euro area data on output growth (ΔGDP_t), annualized domestic inflation (INF_t), nominal interest rates (INT_t) from 1979Q1 up to 2008Q3. [9]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, Henry, and Mestre, 2001).[10,11]

The data are linked to the recursive equations derived under simple rule and optimal policy through a measurement equation specified as:

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

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. For the simple rule with a Markov-switching inflation target, π^A is weighted average of a high π^H and low π^L inflation targets. Due to the presence of Markov-switching parameters, the likelihood function is approximated using Kim (1994)'s filter, and then combined with the prior distribution to obtain the posterior distribution. A random walk Metropolis-Hastings algorithm is then used to generate 2500,000 draws from the

[9]We consider the implications of estimating the model over shorter and longer sample periods in Appendix A.

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

[11]It would be interesting to extend the analysis to the case of real-time data. We leave this extension for future work.

posterior distribution with the first 1000,000 draws being discarded and save every 50th draw from the remaining draws.[12]

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

4.1 Prior Distributions

The priors are presented in Table 1. 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 labor 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. It is important to note that the above priors are common to all model variants.

In addition, variances of shocks are chosen to be highly dispersed inverted Gamma distributions, and the priors for shock variances are set to be symmetric across regimes.

Furthermore, for models featuring a simple rule, the Markov-switching rule parameters are set in line with Bianchi (2012). The priors for the response to output growth and the smoothing term are set to be symmetric across regimes, while asymmetric priors are chosen for the response to inflation. For optimal policy, the relative weights (i.e. $\omega_1, \omega_{2,}\omega_3$) on the objective function are assumed to be distributed following beta distributions and ω_π is allowed to switch between 1 and a value lower than 1, the beta distribution is used for the latter with a mean of 0.5.

For the simple rule with Markov-switching inflation target, the priors for the inflation targets are set in line with Schorfheide (2005). Finally, the average real interest rate, r^A, is linked to the discount factor, β, such that $\beta = \left(1 + r^A/400\right)^{-1}$.

4.2 Posterior Estimates

In this subsection we contrast results when monetary policy is described by an inertial Taylor rule for interest rates, with those obtained when policy is based on one of the notions of optimality,

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

namely discretion and commitment. 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.[13] The first column of results in Table 2 is for the best-fitting model, which is time-consistent discretionary policy, followed by a simple rule with shifts in rule parameters, commitment, and then another simple rule with shifts in the inflation target. Table 2 also reports the Bayes Factors for each model relative to the first model in the Table. 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'.[14] Therefore, the result suggests that there is no significant degree of commitment within Euro-area monetary policy.

If we consider individual parameter estimates obtained under the conventional inertial interest rate rule, then our results are broadly in line with other studies: an intertemporal elasticity of substitution, σ, of 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 labor supply elasticity of $\varphi = 2.478$. Moving from these estimates obtained under a standard interest rate rule to the case of optimal policy under discretion, these deep parameter estimates remain largely the same, except that there is a 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, the simple rule relies on taste shocks (both in terms of size and persistence) to explain the volatility in the data, while the estimates obtained when assuming time-consistent policy significantly raises the estimated size and persistence of cost-push shocks in order to fit the data. These subtle shifts in estimated parameters across optimal 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 and inflation.[15] Accordingly, there is more emphasis on inflation inertia and cost

[13] The application of the Iskrev (2010) local identification test to the model with constant parameters, based on simple rules and optimal policy under discretion and commitment, is supportive of identification.

[14] 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.

[15] 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 inflation inertia and a habits externality which means that taste and technology shocks also imply interesting policy trade-offs - see Leith, Moldovan, and Rossi (2012) for a discussion.

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 stabilization bias (see (Svensson, 1997)) and the parameter estimates slightly raise the extent of habits, $\theta = 0.668$ as well as the variance ($\sigma^2_{\mu(s=1)} = 1.360$, $\sigma^2_{\mu(s=2)} = 1.743$) and persistence ($\rho^\mu = 0.986$) of cost-push shocks.[16] Again this is to help the model achieve a meaningful trade-off for the policy maker and thereby explain the realised movements in output and inflation. Despite this, as we shall see below, the commitment policy is simply too effective in stabilizing the economy, particularly in terms of inflation, to be a reasonable description of the data.

We now turn to consider how the policy making process has changed over time and find for all monetary policy specifications considered, we are able to identify a second 'weak' or 'less conservative' inflation targeting regime. Under commitment and discretion, this is characterised by lowering the weight on inflation stabilization from 1 to 0.271 and 0.547, respectively. Under the simple rule framework, it is captured by either a less active rule or a higher inflation target.[17] The timing and probability of the 'weak' inflation targeting regime are shown in Figure 2. 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 estimates. 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 criticized 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 were harming their economies.[18] 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

[16] It should be noted that the 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.

[17] It is interesting to note that, despite the fact that our estimation technique allows the interest rate rule to switch between an active and passive targeting of inflation, in the less conservative regime the interest rate rule remains mildly active with coefficient on excess inflation of $\psi_1 = 1.16$.

[18] 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 September 5th and 6th, 1992.

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 2. It shows broadly similar patterns of high volatility regime in the early years of the ERM. There are then two additional peaks of 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 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 shall consider counterfactuals relating to the financial crisis observed beyond this sample period in Section 6 below.

5 Counterfactual Analysis

Our best-fitting model is obtained under discretionary policy with Markov switching in the weight on inflation stabilization 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 stabilize volatilities in the Euro-area output and inflation. Furthermore, we can explore how much welfare would have improved had the policy maker been able to act under commitment, and alternative delegation schemes that can be used as a means of capturing some of the gains to commitment.

5.1 Good Luck versus Good Policy

We compute the unconditional variances of key variables, as well as the value of unconditional welfare under alternative counterfactuals. Following Bianchi (2012), we use the unconditional variances of key variables (and the associated welfare losses) computed under the worst case scenario as the benchmark case for the 'good luck' versus 'good policy' debate. That is our 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 stabilize inflation, output and interest rates. Table 3 shows that under discretion an increase in central bank conservatism (i.e. $\omega_\pi = 1$) alone would reduce more than half of 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 also a significant 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', being able to act with commitment can allow central banks to almost completely stabilize inflation volatility, but at the cost of moderate increases in output fluctuations. It is also important to note that welfare is clearly improved regardless of whether the estimated increase in central bank conservatism took 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 weight given to inflation stabilization in the policy maker's objective function i.e. the 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.

In the next section we discuss the ability of alternative delegation schemes to improve upon discretion even without access to a commitment technology and find that substantial welfare gains are possible.

5.2 Alternative Delegation Schemes

As shown in the previous section the gains to commitment are very significant for the Euro area. However, since the empirical analysis finds that there is no evidence of those economies respective central banks being able to implement such commitment policies, in this section we turn to consider whether similar gains can be achieved through alternative delegation schemes which do not pre-suppose an ability to behave in a time-inconsistent manner. Several such schemes 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. For example, Jensen (2002) suggests that policy makers should target nominal GDP growth. Vestin (2006) finds, in the context of a forward-looking model, that price level targeting can bring the equilibrium outcomes close to those found under commitment. While Walsh (2003) argues in favour of Speed Limit policies which retain the inflation target, but replace the quadratic term in the output gap in the objective function with the growth in the output gap. These alternative delegation schemes can all potentially outperform standard inflation targeting under discretion, but their ability to do so depends crucially on the structure of the economy and the nature of the shocks it is subject to.

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.[19] 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 expectations, 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 stabilization for the monetary policy maker i.e. cost push shocks. In contrast, technology shocks which typically 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. Accordingly, we now turn to consider how our economies would have performed had policy makers acted in accordance with these alternative policy regimes. In analyzing such schemes the literature typically adopts one of two approaches depending on whether the delegated target is considered to be 'strict' or 'flexible'. However, as Jensen (2002) notes it is rare for the strict variants of the delegation schemes to outperform discretionary policy using the maximization of social welfare as its objective. Accordingly, we follow the papers cited above in undertaking flexible versions of price level, speed limit and nominal income growth targets, respectively.

Social Welfare

In designing our delegation schemes 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 consider three possible choices in doing so. Firstly, we can consider the micro-founded objective function, implied by the second order approximation to household utility, evaluated using the weights implied by the structural equation estimates,

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

[19] 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.

Secondly, we assume that social welfare is identical to the estimated objective function with the relative weight on inflation targeting term being 1 and ω_1, ω_2 and ω_3 are estimates from our best fitting model

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

Thirdly, we allow for the possibility that society had employed a 'conservative' central banker as in Rogoff (1985) to optimize the outcomes under discretion, whose preferences mirror the above estimated objective function. We then backward engineer society's preferences which implies a lower degree of inflation conservatism,

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

where the 'revealed preference' weight on inflation stabilisation, given our estimated parameters, is calculated to be $\omega_{rp} = 0.206$. This weight implies that it would be optimal to delegate policy to a conservative central banker with a weight on inflation of 1, *cet. par.*.

Moving across these alternative measures of society's welfare significantly reduces the weight we would assume society attaches to inflation stabilization, relative to the real elements in its welfare function. Using the micro-founded social welfare function, it would imply the weight attached to inflation stabilization would be over 100 time larger than those attached to other terms. Such a large weight would effectively result in all optimized delegation schemes being negligibly different from a policy of strict inflation targeting. In contrast the estimated and 'revealed preference' measures of social welfare assume that the society has far less degrees of inflation aversion with the weight attached to inflation being 1 and $\omega_{rp} = 0.206$, respectively.

Alternative Delegation Schemes

We also consider four alternative delegation schemes that a central bank can implement to improve the outcomes under discretionary monetary policy. These include inflation targeting, nominal income growth targeting, speed limit policies and price level targeting. Within each case we optimize the weights on the delegated targets. Therefore, in the case of inflation targeting, we retain the weights on the real terms, ω_1, ω_2, and ω_3 to be consistent with the estimates from our best fitting model, while ω_π is selected in order to maximize the respective social welfare metrics discussed above,

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

In considering both price level and nominal income growth targeting we replace the inflation term with the alternative targets, such that the delegated objectives under price level targeting are the following,

$$\Gamma_p = -\overline{N}^{1+\varphi}\frac{1}{2}\mathbb{E}_0\sum_{t=0}^{\infty}\beta^t\left\{\omega_1\left(\widehat{X}_t+\widehat{\xi}_t\right)^2+\omega_2\left(\widehat{y}_t-\frac{\sigma}{\varphi}\widehat{\xi}_t\right)^2+\omega_3\left(\Delta\widehat{R}_t\right)^2+\omega_p\widehat{p}_t^2\right\},$$

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

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

where $\widehat{y}_t-\widehat{y}_{t-1}+z_t+\widehat{\pi}_t$ captures the growth in nominal GDP relative to its trend. Finally, when implementing speed limit policies we follow Walsh (2003) who retains the inflation target, but alters the real element in the policy maker's objective function to give,

$$\Gamma_{SL} = -\overline{N}^{1+\varphi}\frac{1}{2}\mathbb{E}_0\sum_{t=0}^{\infty}\beta^t\left\{(\widehat{\pi}_t^2+\frac{\zeta\alpha^{-1}}{(1-\zeta)}\left[\widehat{\pi}_t-\widehat{\pi}_{t-1}\right]^2)+\omega_3\left(\Delta\widehat{R}_t\right)^2+\omega_{SL}(\widehat{y}_t-\widehat{y}_{t-1})^2\right\},$$

As with inflation targeting, we choose ω_p, ω_{NI} and ω_{SL} within each delegation scheme to achieve maximum social welfare. To do so, we randomly select 200 draws from our posterior distribution of parameters and for each draw we obtain the optimized weight for each delegation scheme and each measure of social welfare. The median of these optimized weights are reported in Table 4 along with the 90% confidence intervals in square brackets.

The optimization of the weights within the various delegation schemes reveals several features of optimal policy. As in the second column of Table 4, the micro-founded social welfare implies a very aggressive response to inflation with inflation and price level targets effectively resulting in strict inflation targeting, while speed limit policies are almost as aggressive. 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. As the optimal delegation schemes, under the micro-founded social welfare, imply a policy of strict inflation targeting, which is clearly unrealistic in terms of real-world policy making we do not pursue this description of social welfare further. The third column in Table 4 presents the optimized weights when the estimated objective function is used as a measure of social welfare with the relative weight on inflation stabilisation being 1. Moving from the micro-founded to the estimated social welfare implies a significant decrease in the weight we assume society attaches to inflation stabilization. This substantially reduces central bank's inflation conservatism with the price level target becoming very flexibly applied (i.e. the weight on the optimized price level term is 0.08.). Furthermore, using 'revealed preferences' as our guide to the design of delegation schemes would imply a even less aggressive response to inflation volatility.[20]

We further consider the macroeconomic outcomes under each of these delegation schemes optimally designed using the estimated and 'revealed preference' measures of social welfare. Using estimated social welfare, Figure 3 shows that all delegation schemes would have substantially reduced inflation in the early 1980s at the expense of moderate output loses. Although the most appropriate target could have been a price level target, albeit with a very low weight on the price level target implying a great deal of flexibility. This is confirmed in Table 5 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 policy in terms of inflation volatility and this is reflected in their welfare performance. The other schemes all perform relatively well, although price level targeting comes closest to achieving the welfare levels attained under commitment. This also implies that this delegation scheme is not just appropriate for good times, but would have yielded substantial benefits under the high volatility regime of the early 1980s too.

Figure 4 performs the same exercise, but using 'revealed preference' social welfare, which would imply a smaller degree of inflation aversion compared to the estimated social welfare measure. Therefore, the schemes are now unable to bring inflation consistently below 5% in the 1980s. Again, the nominal income growth target is particularly bad in stabilizing inflation. Taken together the results in Tables 5 and 6, suggest that regardless of the volatility regime and social welfare measures we use, flexible price level targeting emerges as the optimal delegation scheme as it comes closest to achieving the welfare levels attained under commitment.

This is also shown in Figure 5, which contrasts the outcomes under inflation and price level

[20] The fact that the data seem to suggest that policy maker preferences are significantly less aggressive than micro-founded loss functions, and that society's preferences are even more so has a counterpart in the conflict between estimated and optimized simple rules. The former suggest that since the early 1980s policy rules are mildly active with long-run coefficients on inflation lying between 1 and 2, while optimized rules (based on microfounded welfare) often restrict the coefficient on excess inflation to avoid optimized values rising to implausibly high levels (see, for example, Schmitt-Grohe and Uribe, 2007).

targets with optimally chosen weights, with the outcomes that would be achieved had society been able to appoint someone who was able to make credible policy commitments and accurately reflected the society's inflation conservatism (i.e. the relative weight attached to inflation stabilisation is $\omega_{rp} = 0.206$). We see that the gains to commitment remain high, even if we assume that inflation targeting under discretion is as good as it can possible be. If, instead, we had given the policy maker the remit of targeting a price level target with an optimally chosen weight, then the outcome would have been far closer to that of commitment.

6 The ECB, the ZLB and the Financial Crisis

In this section we examine the ECB's policy response to the financial crisis. In utilizing the LQ framework for estimation and policy analysis we have implicitly been assuming that there was no significant zero lower bound (ZLB) constraint. While this was true over the estimation period, the financial crisis outwith our sample shows that this is clearly not always the case. Therefore in examining the ECB's recent behavior and how our delegation schemes would have fared in the face of the crisis, we need to take account of the ZLB.

Given the number of state variables in our model, including lagged output, inflation and interest rates, and three AR(1) shock processes, it is computationally difficult to account for the ZLB using global solution methods as in Adam and Billi (2008), Adam and Billi (2007) and Nakov (2008). Therefore, following Erceg and Linde (Erceg and Linde) and Bodenstein et al. (2013) we use the procedure in Laseen and Svensson (2011), who propose a convenient algorithm to construct policy projections conditional on alternative anticipated policy rate paths in linearized DSGE models. This algorithm involves adding a vector of anticipated policy shocks to the policy rule so that the actual and expected paths of the nominal interest rate do not fall below the ZLB for any given initial state of the economy in perfect foresight simulations. Laseen and Svensson (2011) compute the optimal ZLB solution under simple rules and commitment. We further extend the algorithm to the case of discretion as shown in Appendix B. Furthermore, we adopt the iteration steps described in Bodenstein et al. (2013) to endogenize the duration of the ZLB period contingent on the realization of particular shocks. Therefore, we are using this device to enable us to conduct counterfactuals which reveal the outcomes of optimal policies under our estimated ECB behavior as well as our various delegation schemes after accounting for endogenously determined periods where interest rates have hit the ZLB.

We begin by assessing how robust our delegation schemes are to the existence of the ZLB using our 'revealed preference' measure of social welfare. To do so, we simulate 100,000 periods using our median parameter estimates from our best fitting model. The sample length is set so that the discount factor is effectively zero by the end of simulation period and adding further periods does not significantly change the discounted loss. We calculate the standard deviation of the variables, the unconditional welfare loss and the frequency at which the ZLB is binding, when the economy is under the low and high volatility regimes, respectively. We consider two scenarios. First, our estimated data averages of 2.8% inflation and 2% annualized output growth. Second we consider a scenario we label the 'New Normal' which reflects the possibility that the Euro area economies have entered a protracted period of low growth. Specifically, under this scenario we assume a 2% inflation target and output growth of 1.5% (see OECD (2012) forecasts to 2030). As shown in Table 7, based on our sample data averages prior to the financial crisis, the ZLB constraint is not an issue as it occurs rarely under all delegation schemes. As a result, the welfare losses under the speed limit and nominal income growth targets due to breaching the ZLB are negligible. However, under the 'New Normal' scenario shown in Table 8, the occurrence of ZLB becomes more frequent under the high volatility regime, and the welfare losses due to this constraint are particularly high under nominal income growth targeting where the ZLB is breached in over 3% of all periods. On the other hand, optimally designed inflation and price level targets remain successful in avoiding the ZLB constraint and, again, flexible price level targeting has the lowest welfare loss amongst all delegation schemes considered. This is in line with the results in Section 5.2.

Given the severity of recent financial crisis, it is also important to assess the outcomes under our delegation schemes in response to the set of specific shocks that drove the economy to recession and the ZLB. To recover these shocks from the observed data, we set Kim (1994)'s filter to run over an extended sample period from 1979Q1 to 2013Q2, conditional on the parameter estimates from our shorter sample period 1979Q1-2008Q3. We term these shocks the 'realized shocks', as in combination with the regime probabilities they allow our model to replicate the data. In identifying these shocks we assume that the Eurozone economy has entered into the 'New Normal' from 2008Q4 onwards, with a reduced underlying growth rate of 1.5% and inflation target of 2%. The top three panels in Figure 6 show the realized shocks. A huge negative technology shock is observed following the collapse of Lehman Brothers. A negative taste shock occurs around the same time implying that households' appetite for consumption falls, and a negative cost-push shock explains why inflation fell rather than rose following the negative technology shock.

The probabilities of less conservative and high volatility regimes are shown in the bottom panel in Figure 6. It reveals that the regime of high volatility reappears over 2008-2009 when the financial crisis intensified following the collapse of Lehman Brothers, and also during 2012-2013, although to a lesser extent, as the sovereign debt crisis in the Euro-area came to a head in 2012. We can also see that the ECB's policy response to falling inflation was not very aggressive such that the ECB appears to have lost conservatism throughout the crisis period, particularly as the sovereign debt phase of crisis deepened in 2012.[21] This suggests that the first wave of the financial crisis in the Eurozone was predominantly driven by the shocks experienced by economies throughout the world, but that the second phase of the crisis, as experienced by the Euro-area economies, was associated with a muted monetary policy response.

We now turn to ask what monetary policy could have done differently during the crisis? To examine this, we insert the 'realized shocks' back into our model assuming that policy was operating under one of our alternative different delegation schemes. We can see from Figure 7 that under optimally designed inflation and price level targets, nominal interest rates would have been away from the ZLB throughout our extended sample period. Therefore, had the ECB maintained its conservatism throughout the crisis, it could have kept inflation close to target without being affected by the ZLB. However, under nominal income growth and speed limit targets, nominal interest rates would have breached the ZLB during the crisis period, for two and six quarters, respectively. Nevertheless, the nominal income growth delegation scheme offsets part of the fall in output more successfully than the other delegation schemes as shown in Figure 7. We compute 'realized welfare', that is, the discounted 'revealed preference' welfare measure given the 'realized shocks' during the crisis period and compare that with the same measure under the alternative delegation schemes, after accounting for the ZLB. This analysis suggests that welfare losses would have been lowest under the nominal income growth targeting by 1.96%, compared to 1.45% and 1.33% under inflation and price level targets.

Therefore, our analysis suggests that, in general flexible price level targeting is our preferred delegation scheme and that this is reinforced by taking account of the ZLB which it typically manages to avoid. However, for the particular shocks we estimate drove the crisis in the Euro-Area, nominal income growth targets would have performed marginally better at the height of the crisis despite the fact they would have breached the ZLB.

[21] If instead, we assume that average historical growth and inflation rates were likely to continue for the extended sample period from 2008Q4 to 2013Q2, then the ECB's behavior in the financial crisis has been even more passive given the observed falls in inflation and output, and the ECB would be labelled as 'less conservative' with a probability close to one throughout the crisis period. These results are available upon request.

7 Robustness

We conducted various robustness exercises which are detailed in Appendix A. Here we simply note that we considered alternative sample periods, the role of interest rate smoothing, the possibility that estimated changes in conservatism reflected structural changes and a form of optimal policy labelled 'quasi-commitment'. In all cases the results and conclusions presented above remain valid.

8 Conclusions

In this paper we explored the implications of describing policy using two notions of optimal policy, namely 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 operated under discretion with several shifts in both the conservatism of monetary policy and the volatility of shocks hitting the economy. These estimates reveal several features of the evolution of Euro-area policy making that are not so readily apparent from estimates based on describing policy with a simple rule. Specifically, it appears as though 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 been lost and regained several times since then. Firstly, in the late 1980s, particularly at the time of German reunification and the subsequent turmoil in the ERM around 'Black Wednesday' in September 1992. Given that German policy makers were often criticized 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 estimated reduction in policy conservatism at the time is striking. Moreover, there appears to have been further relaxations in the policy stance a few years before the launch of the Euro and for much of the first decade of the Euro's existence.

Based on estimates from our best-fit model, we undertake a range of counterfactual simulations which throw light on various aspects of policy. Firstly, 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, although since increased conservatism implied output losses as the price for this reduction in inflation, the welfare gains from good luck were substantially higher. However, when we considered what would have happened had policy makers had the ability to commit then, even without any changes in shock volatilities or conservatism the welfare gains would be huge - inflation would never have risen above 5% in the 1980s.

Given the potential gains to improving the credibility of policy making, we considered to what extent alternative delegation schemes - price level targets, inflation targets, speed limit policies and nominal income growth targets - would have improved policy outcomes. We use three different social welfare metrics to design our alternative central bank remits. Using micro-founded welfare we find that policy outcomes are very close to strict inflation targeting. Under our estimated and 'revealed preference' social welfare, the optimal delegation scheme turns out to be a version of flexible price level targeting, despite the presence of habits and inflation inertia in the underlying model. The dominance of this scheme applies whether or not we are in the high or low volatility regime.

Finally, our examination of the ECB's behavior during the recent financial and sovereign debt crises, suggests that the first wave of the crisis was driven by the global contagion that followed the collapse of Lehman Brothers, but that the second wave observed in the Euro area in 2012 was more likely caused by a weak policy response to falling Euro-area output and inflation. Counterfactual simulations suggest that the ECB could have brought inflation far closer to the target in this period without breaching the ZLB had it retained its 'conservatism' and been expected to respond more aggressively to falling inflation. Our ranking of alternative delegation schemes also remains intact after accounting for the existence of the ZLB. In particular, flexible price level targeting is still optimal even if lower long-term growth has become the 'New Normal'. However, at the peak of the crisis, nominal income growth targets would have mitigated the fall in output and been welfare improving at that point in time.

In future work we would seek to extend the analysis to a richer medium-scale model of the Euro-area economy, as well as considering the implications of the policy maker relying on real time data when implementing policy.

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A Robustness

We have undertaken various robustness exercises, which are discussed below.

A.1 Interest Rate Smoothing

Our benchmark results all found that there was a non-trivial role for interest rate smoothing in the policy maker's objective function. Such terms are often included in normative analyses as they serve to introduce an element of history dependence to discretionary policy making which can help such policies mimic commitment (see Woodford (2003)). Since our delegation schemes can, to varying degrees, move policy closer to commitment it is interesting to ask to what extent this is due to the inclusion of interest rate smoothing in the delegated objective function. To do so we recompute the optimal delegation schemes after restricting the weight on the interest rate smoothing term to be zero under estimated and 'revealed preference' social welfare metrics. In both cases this has a negligible impact on the functioning of all delegation schemes other than nominal income targeting where the interest rate smoothing term helps prevents an inappropriate policy response. In all other delegation schemes the role played by interest rate smoothing is minimal.

We should also note that an earlier version of the paper (Chen et al., 2013b), using a longer sample period, also did not allow a role for interest rate smoothing. Although allowing for such an element in the objective function is preferred by the data, and therefore included in our benchmark results, it again did not affect the conclusion that discretion was the preferred description of policy.

A.2 Sample Periods and Switches in Policy Type

We have considered alternative sample sizes, either beginning in the early 1970s or in 1994. The former were considered in a previous version of the paper Chen et al., 2013a, and the latter are available upon request. Using a sample period beginning in the early 1970s does not affect the conclusion that discretion decisively ahead of all other policy descriptions remains, and flexible price level targets can bring the outcomes under a delegated policy close to those under commitment,

We then considered a shorter sample period beginning in 1994. This is to investigate whether or not commitment policy becomes a data preferred description of policy making when we focus on the recent data period. However, the ranking across policy types is unchanged.

A.3 Structural Change

We also allowed for Markov switching in the degree of price stickiness. This is to assess whether or not the switches in conservatism were picking up a rational policy response to fluctuations in the extent of nominal inertia. Here we found that allowing for such structural change did not generate any significant changes in estimates of the Calvo parameter, but the switches in conservatism were still present in the estimation.

A.4 Quasi-Commitment

As the extreme of full commitment may be considered to be unattainable, we also considered an intermediate case of quasi-commitment. (Schaumburg and Tambalotti (2007), Debertoli and Nunes (2010) and Himmels and Kirsanova (2013) all provide theoretical discussions of this description of policy.) Under quasi-commitment, the policy maker deviates from full commitment-based plans with a fixed probability (which is known by the private sector). Effectively, the policy maker forms a commitment plan which they will adhere to until randomly ejected from office. At which point a new policy maker will be appointed, and a new plan formulated (based on the same objective function) until that policy maker is, in turn, removed. Therefore, the central bank can neither completely control the expectations of the private sector, nor can she perfectly coordinate the actions of all future policy makers. This framework incorporates elements of both discretion and commitment.

Specifically, we followed Himmels and Kirsanova (2013) in recasting the quasi-commitment of Schaumburg and Tambalotti (2007) and Debertoli and Nunes (2010) in a general linear-quadratic form which can be solved using standard iterative techniques, such as Söderlind (1999). Such a description of policy contains both discretion and commitment as special cases. However, despite being intuitively appealing as an intermediate case, quasi-commitment and the associated expectational errors the policy implies, are not a data-preferred description of policy. We therefore, to save space, do not report the results obtained under quasi-commitment.

B Imposing the ZLB on the Policy Rate Projection

Laseen and Svensson (2011) propose a convenient algorithm to construct policy projections conditional on alternative anticipated policy rate paths in linearized DSGE models. The algorithm expands the set of predetermined variables by adding a vector of future policy shocks to a given policy rule, that satisfies the anticipated policy rate path. Laseen and Svensson (2011) illustrate how to add an anticipated sequence of shocks to the solution under both commitment and a simple rule. We extend this algorithm to the case of discretion.

Our model in equations 5 and 12 can be written in the following state-space form

$$\boldsymbol{X}_{t+1} = \boldsymbol{A}_{11}\boldsymbol{X}_t + \boldsymbol{A}_{12}\,\boldsymbol{x}_t + \boldsymbol{B}_1\,\boldsymbol{i}_t + \boldsymbol{C}\boldsymbol{\varepsilon}_{t+1} \tag{16}$$

$$\boldsymbol{H}\boldsymbol{x}_{t+1} = \boldsymbol{A}_{21}\boldsymbol{X}_t + \boldsymbol{A}_{22}\,\boldsymbol{x}_t + \boldsymbol{B}_2\,\boldsymbol{i}_t, \tag{17}$$

where $\boldsymbol{X}_t$ is a n_1 vector of predetermined variables; $\boldsymbol{x}_t$ is a n_2 vector of forward-looking variables; $\boldsymbol{i}_t = \left[\widehat{R}_t\right]$ is the control variable, and $\boldsymbol{\varepsilon}_t$ contains a vector of zero mean *i.i.d.* shocks. Without loss of generality, the shocks are normalized so that the covariance matrix of $\boldsymbol{\varepsilon}_t$ is the identity matrix, $\boldsymbol{I}$. Therefore, the covariance matrix of the shocks to $\boldsymbol{X}_{t+1}$ is $\mathbf{CC}'$.

The central bank has an intertemporal loss function in period t :

$$\mathbb{E}_t \sum_{s=t}^{\infty} \frac{1}{2}\beta^{s-t}\boldsymbol{L}_s,$$

where the period loss, L_s, satisfies

$$\boldsymbol{L}_s = \mathbf{Y}_s' \boldsymbol{\Lambda} \mathbf{Y}_s,$$

$\boldsymbol{\Lambda}$ is a symmetric and positive semidefinite weight matrix and $\boldsymbol{Y}_s$ is an n_Y vector of target variables

$$\boldsymbol{Y}_s = \boldsymbol{D} \begin{bmatrix} \boldsymbol{X}_s \\ \boldsymbol{x}_s \\ i_s \end{bmatrix}.$$

It follows that the period loss function can be rewritten as

$$L_s = \begin{bmatrix} \boldsymbol{X}_s \\ \boldsymbol{x}_s \\ \boldsymbol{i}_s \end{bmatrix}' \boldsymbol{W} \begin{bmatrix} \boldsymbol{X}_s \\ \boldsymbol{x}_s \\ \boldsymbol{i}_s \end{bmatrix},$$

where $\boldsymbol{W} = \boldsymbol{D}'\boldsymbol{\Lambda}\boldsymbol{D}$ is symmetric and positive semidefinite, and

$$\boldsymbol{W} = \begin{bmatrix} Q_{XX} & Q_{Xx} & P_{Xi} \\ Q_{Xx}' & Q_{xx} & P_{xi} \\ P_{Xi}' & P_{xi}' & R \end{bmatrix}$$

is partitioned with $\boldsymbol{X}_s$, $\boldsymbol{x}_s$ and $\boldsymbol{i}_s$.

Following Laseen and Svensson (2011), we augment the predetermined variables, $\boldsymbol{X}_t$, in equations 16-17 by incorporating a $(T+1)$ vector of stochastic shocks, $\boldsymbol{z}^t \equiv (z_{t,t}, z_{t+1,t} \dots z_{t+T,t})'$,which denote a projection in period t of future realizations of shocks, $z_{t+\tau,t}, \tau = 0, 1, ..., T$. Furthermore, we assume that $z_{t,t}$ follows a moving average process

$$z_{t,t} = \eta_{t,t} + \sum_{s=1}^{T} \eta_{t,t-s},$$

where $\eta_{t,t-s}, s = 0, 1, ..T$, are zero-mean *i.i.d.* shocks. For $T = 0$, $z_{t,t} = \eta_{t,t}$. For $T > 0$, the stochastic shocks following a moving average process:

$$\begin{aligned} z_{t+\tau,t+1} &= z_{t+\tau,t} + \eta_{t+\tau,t+1}, \ \tau = 1, ..., T \\ z_{t+T+1,t+1} &= \eta_{t+T+1,t+1}. \end{aligned}$$

The above stochastic shocks process can be rewritten in the following matrix form

$$\boldsymbol{z}^{t+1} = \mathbf{A}_z \boldsymbol{z}^t + \boldsymbol{\eta}^{t+1},$$

where $\boldsymbol{\eta}^{t+1} \equiv (\eta_{t+1,t+1}, \eta_{t+2,t+1} \cdots \eta_{t+T+1,t+1})'$ is a $(T+1)$ vector of *i.i.d.*shocks and A_z is $(n_1+1) \times (n_1+1)$ matrix

$$A_z = \begin{bmatrix} \mathbf{0}_{T\times 1} & \boldsymbol{I}_T \\ 0 & \mathbf{0}_{1\times T} \end{bmatrix}$$

Our model (16) incorporating the vector of stochastic shocks, $\boldsymbol{z}^t$, is subsequently augmented into the following state-space form

$$\widetilde{\boldsymbol{X}}_{t+1} = \widetilde{A}_{11}\widetilde{\boldsymbol{X}}_t + \widetilde{A}_{12}\boldsymbol{x}_t + \widetilde{B}_1\boldsymbol{i}_t + \widetilde{C}\boldsymbol{\varepsilon}_{t+1} \tag{18}$$

$$\boldsymbol{H}\boldsymbol{x}_{t+1} = \widetilde{A}_{21}\widetilde{\boldsymbol{X}}_t + \widetilde{A}_{22}\boldsymbol{x}_t + \widetilde{B}_2\boldsymbol{i}_t \tag{19}$$

where $\widetilde{\boldsymbol{X}}_t = \left[\boldsymbol{z}^t, \boldsymbol{X}_t'\right]'$ is a vector of predetermined variables. The matrices of the state-space are augmented accordingly

$$\begin{aligned}
\widetilde{A}_{11} &= \begin{bmatrix} A_z & 0_{T+1,n1} \\ 0_{n_1\times T+1} & A_{11} \end{bmatrix}, \widetilde{A}_{12} = \begin{bmatrix} 0_{T+1\times n_2} \\ A_{12} \end{bmatrix}, \\
\widetilde{A}_{21} &= \begin{bmatrix} 0_{n_2\times T+1} & A_{21} \end{bmatrix}, \widetilde{A}_{22} = A_{22}, \\
\widetilde{B}_1 &= \begin{bmatrix} 0_{T+1\times 1} \\ B_1 \end{bmatrix}, \widetilde{B}_2 = B_2.
\end{aligned}$$

The selection matrix $\boldsymbol{D}$ becomes $\widetilde{\boldsymbol{D}} = \begin{bmatrix} 0_{n_Y\times T+1} & \boldsymbol{D} \end{bmatrix}$. Subsequently, the symmetric and positive semidefinite weight matrix is now defined as $\widetilde{\boldsymbol{W}} = \widetilde{\boldsymbol{D}}'\boldsymbol{\Lambda}\widetilde{\boldsymbol{D}}$, where

$$\widetilde{\boldsymbol{W}} = \begin{bmatrix} \widetilde{Q}_{XX} & \widetilde{Q}_{Xx} & \widetilde{P}_{Xi} \\ \widetilde{Q}_{Xx}' & \widetilde{Q}_{xx} & \widetilde{P}_{xi} \\ \widetilde{P}_{Xi}' & \widetilde{P}_{xi}' & \widetilde{R} \end{bmatrix}$$

is partitioned with $\widetilde{\boldsymbol{X}}_s$, $\boldsymbol{x}_s$ and $\boldsymbol{i}_s$.

To impose the ZLB constraint on the nominal interest rate $\boldsymbol{i}_t = \left[\widehat{R}_t\right]$,we set the first element in $\widetilde{P}_{Xi}'$ to -1 to load $z_{t,t}$, which is the first element in the vector of predetermined variables $\widetilde{\boldsymbol{X}}_t = \left[z^t, \boldsymbol{X}_t'\right]'$.The projection of the future stochastic shocks is then chosen to ensure that $r^A + \pi^A + 4\gamma^Q + 4\widehat{R}_t \geqslant ZLB$, for $\tau = 0, 1, ..., T$. Here, we set $ZLB = 0.25\%$.

Suppose that the reaction of the private sector is given by the following linear rule

$$\boldsymbol{x}_{t+1} = -N\widetilde{\boldsymbol{X}}_{t+1}, \tag{20}$$

We can rewrite equation (20) into an equivalent form in terms of predetermined variables and controls (as did Oudiz and Sachs, 1985) by substituting for $\widetilde{\boldsymbol{X}}_{t+1}$ using (18):

$$\boldsymbol{x}_{t+1} = -N\widetilde{\boldsymbol{X}}_{t+1} = -N(\widetilde{A}_{11}\widetilde{\boldsymbol{X}}_t + \widetilde{A}_{12}\boldsymbol{x}_t + \widetilde{B}_1\boldsymbol{i}_t).$$

Combining this with equation (19) we obtain:

$$\boldsymbol{x}_t = -J\widetilde{\boldsymbol{X}}_t - K\boldsymbol{i}_t,$$

where

$$J = \left(HN\widetilde{A}_{12} + \widetilde{A}_{22}\right)^{-1}\left(\widetilde{A}_{21} + HN\widetilde{A}_{11}\right), \tag{21}$$

$$K = \left(HN\widetilde{A}_{12} + \widetilde{A}_{22}\right)^{-1}\left(\widetilde{B}_{2} + HN\widetilde{B}_{1}\right) \tag{22}$$

The policymaker maximizes its objective function with respect to $\boldsymbol{i}_t$, taking the time-consistent reaction $\boldsymbol{x}_t$ as given, and recognising the dependence of $\boldsymbol{x}_t$ on policy $\boldsymbol{i}_t$. We define the following Lagrangian with constraints capturing the evolution of the state variables in the economy, as well as the private sector's response to policy,

$$H_s = \mathbb{E}_t \sum_{s=t}^{\infty} \frac{1}{2}\beta^{s-t}\boldsymbol{L}_s + \lambda'_{s+1}\left(\widetilde{A}_{11}\widetilde{\boldsymbol{X}}_s + \widetilde{A}_{12}\boldsymbol{x}_s + \widetilde{B}_1\boldsymbol{i}_s - \widetilde{\boldsymbol{X}}_{s+1}\right) + \mu'_s\left(\boldsymbol{x}_s + J\widetilde{\boldsymbol{X}}_s + K\boldsymbol{i}_s\right),$$

where λ_s and μ_s are Lagrange multipliers. First order conditions are the following

$$\begin{aligned}
\frac{\partial H_s}{\partial \boldsymbol{i}_s} &= \beta^{s-t}\left(\widetilde{P}'_{Xi}\boldsymbol{X}_s + \widetilde{P}'_{xi}\boldsymbol{x}_s + \widetilde{R}i_s\right) + \widetilde{B}'_1\lambda_{s+1} + K'\mu_s = 0\\
\frac{\partial H_s}{\partial \widetilde{\boldsymbol{X}}_s} &= \beta^{s-t}\left(\widetilde{Q}_{XX}\boldsymbol{X}_s + \widetilde{Q}_{Xx}\boldsymbol{x}_s + \widetilde{P}_{Xi}i_s\right) + \widetilde{A}'_{11}\lambda_{s+1} - \lambda_s + J'\mu_s = 0\\
\frac{\partial H_s}{\partial \boldsymbol{x}_s} &= \beta^{s-t}\left(\widetilde{Q}'_{Xx}\boldsymbol{X}_s + \widetilde{Q}_{xx}\boldsymbol{x}_s + \widetilde{P}_{xi}i_s\right) + \widetilde{A}'_{12}\lambda_{s+1} + \mu_s = 0\\
\frac{\partial H_s}{\partial \lambda_{s+1}} &= \widetilde{A}_{11}\widetilde{\boldsymbol{X}}_s + \widetilde{A}_{12}\boldsymbol{x}_s + \widetilde{B}_1\boldsymbol{i}_s - \widetilde{\boldsymbol{X}}_{s+1} = 0\\
\frac{\partial H_s}{\partial \mu_{s+1}} &= \boldsymbol{x}_s + J\widetilde{\boldsymbol{X}}_s + K\boldsymbol{i}_s = 0
\end{aligned}$$

By substituting out μ_s and $\boldsymbol{x}_s$ from the above equations, we obtain the following three equations:

$$\begin{aligned}
\beta B^{*\prime}\boldsymbol{\xi}_{s+1} &= -P^{*\prime}\widetilde{\boldsymbol{X}}_s - R^{*}\boldsymbol{i}_s,\\
\beta A^{*\prime}\boldsymbol{\xi}_{s+1} &= -Q^{*}\widetilde{\boldsymbol{X}}_s - P^{*}_s\boldsymbol{i}_s + \boldsymbol{\xi}_s,\\
\widetilde{\boldsymbol{X}}_{s+1} &= A^{*}\widetilde{\boldsymbol{X}}_s + B^{*}\boldsymbol{i}_s,
\end{aligned}$$

where $\xi_s = \beta^{-s+t}\lambda_s$, $\xi_{s+1} = \beta^{-s-1+t}\lambda_{s+1}$, and

$$\begin{aligned}
Q^* &= \widetilde{Q}_{XX} - \widetilde{Q}_{Xx}J - J'\widetilde{Q}_{xX} + J'\widetilde{Q}_{xx}J, \\
P^* &= J'\widetilde{Q}_{xx}K - \widetilde{Q}_{Xx}K + \widetilde{P}_{Xi} - J'\widetilde{P}_{xi}, \\
R^* &= K'\widetilde{Q}_{xx}K + \widetilde{R} - K'\widetilde{P}_{xi} - \widetilde{P}'_{xi}K, \\
A^* &= \widetilde{A}_{11} - \widetilde{A}_{12}J, \\
B^* &= \widetilde{B}_1 - \widetilde{A}_{12}K.
\end{aligned}$$

These then can be cast into the following matrix form

$$\begin{bmatrix} I & 0 & 0 \\ 0 & 0 & \beta B^{*\prime} \\ 0 & 0 & \beta A^{*\prime} \end{bmatrix} \begin{bmatrix} \widetilde{\boldsymbol{X}}_{t+1} \\ \boldsymbol{i}_{t+1} \\ \boldsymbol{\xi}_{t+1} \end{bmatrix} = \begin{bmatrix} A^* & B^* & 0 \\ -P^{*\prime} & -R^* & 0 \\ -Q^* & -P^* & I \end{bmatrix} \begin{bmatrix} \widetilde{\boldsymbol{X}}_t \\ \boldsymbol{i}_t \\ \boldsymbol{\xi}_s \end{bmatrix} \tag{23}$$

A solution to linear system (23) will necessarily have a linear form of

$$\begin{bmatrix} \boldsymbol{i}_t \\ \boldsymbol{\xi}_t \end{bmatrix} = \begin{bmatrix} -F \\ S \end{bmatrix} \widetilde{\boldsymbol{X}}_t \tag{24}$$

It is straightforward to show that system matrices in (24) satisfy the following Riccati equations describing the solution to the discretionary policy problem.

$$S = Q^* + \beta A^{*\prime} S A^* - \left(P^{*\prime} + \beta B^{*\prime} S A^*\right)\left(R^* + \beta B^{*\prime} S B^*\right)^{-1}\left(P^{*\prime} + \beta B^{*\prime} S A^*\right) \tag{25}$$

$$F = \left(R^* + \beta B^{*\prime} S B^*\right)^{-1}\left(P^{*\prime} + \beta B^{*\prime} S A^*\right) \tag{26}$$

To sum up, our ZLB algorithm under discretion constrains the nominal interest rate to remain at ZLB during the periods where particular shocks drive the nominal interest rate below ZLB, otherwise the interest rate is not bounded. To endogenize the duration of the ZLB period contingent on particular shocks, we adopt the iteration steps described in Bodenstein et al. (2013). This procedure initially chooses the periods that ZLB binds by setting a sequence of $\eta_{t,t-s}$,based on the periods during which interest rates would fall below ZLB when no such constraint was imposed. It then revises the sequence of $\eta_{t,t-s}$ to withdraw the ZLB constraint in periods where the interest rates turn out to be above ZLB in the chosen periods. We find that Bodenstein et al. (2013)'s iteration steps work well with our model and our ZLB algorithm. It converges in under ten iterations in the case of speed limit policies and nominal income growth targets when ZLB constraints are breached.

Technical Appendix (Not for publication)

A The Complete Model

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

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

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-linearization. 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

$$N^{\sigma+\varphi}(1-\theta)^{\sigma} = w(1-\tau). \tag{27}$$

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 labor 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 decentralized equilibrium. The social planner ignores the nominal inertia and all other inefficiencies and chooses real allocations that maximize 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 labor 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

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

If we contrast this with the allocation achieved in the steady-state of our decentralized equilibrium, see (27) 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, $c_t = C_t/A_t$.

Linearization up to second order yields

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

where where $tip(3)$ includes terms independent of policy of third order and higher and 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

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

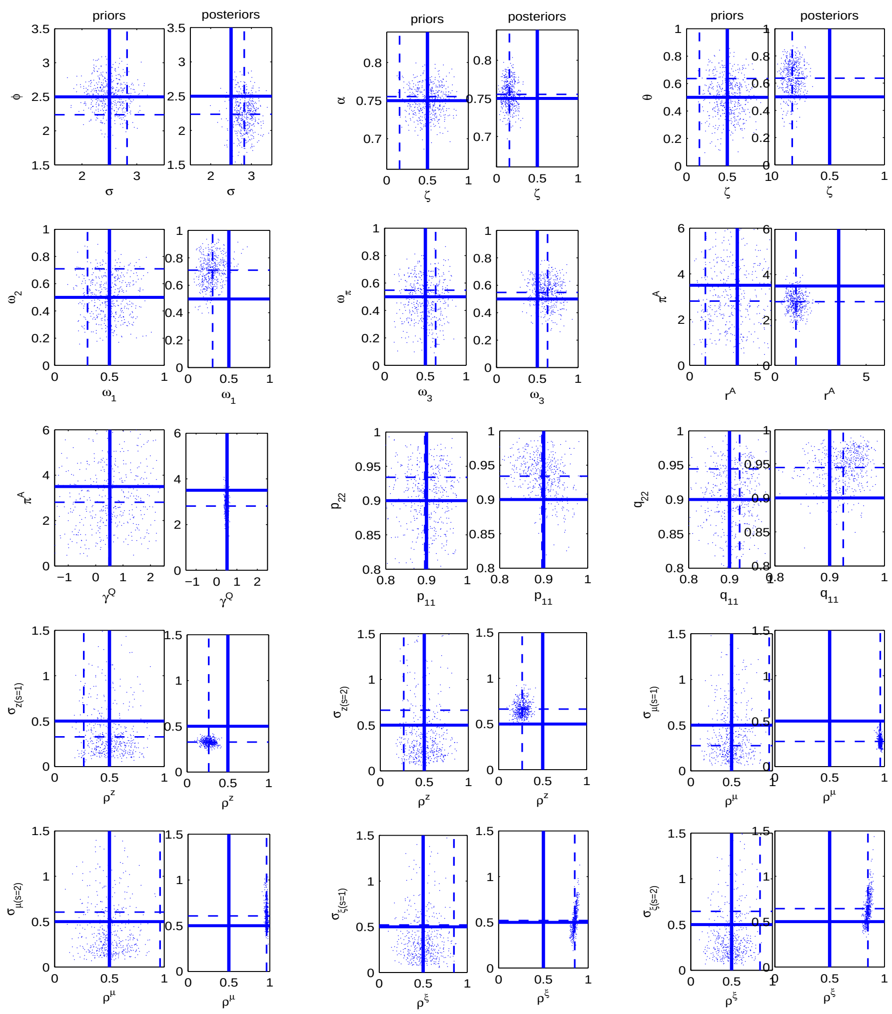
The second order approximation to the national income identity yields

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

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

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

Figure 1: Prior and Posterior Distributions of Parameters



Notes: The panels depict 500 draws from prior and posterior distributions from the estimates in the first column of Table 4. The draws are plotted for pairs of estimated parameters and the intersections of lines signify prior (solid) and posterior (dashed) means, respectively.

Figure 2: Markov Switching Probabilities - Policy and Volatility Switches

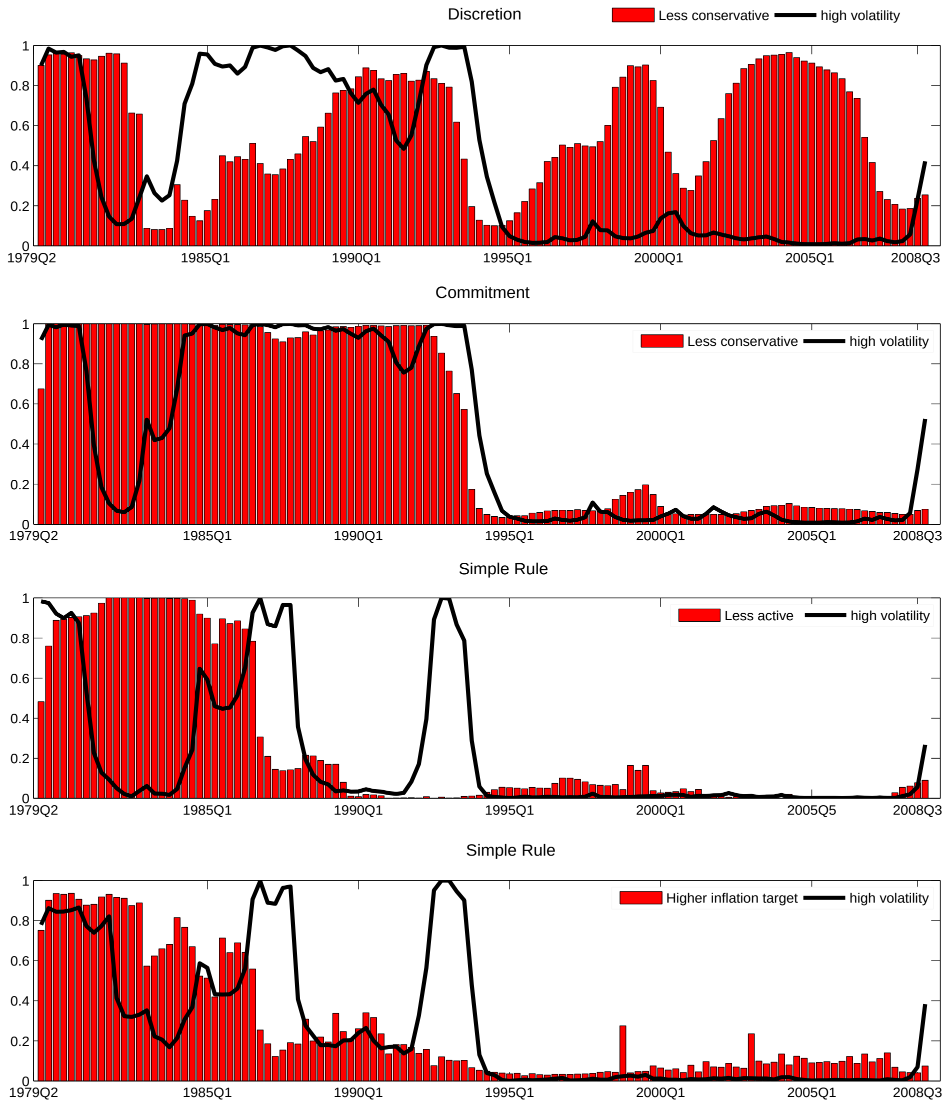
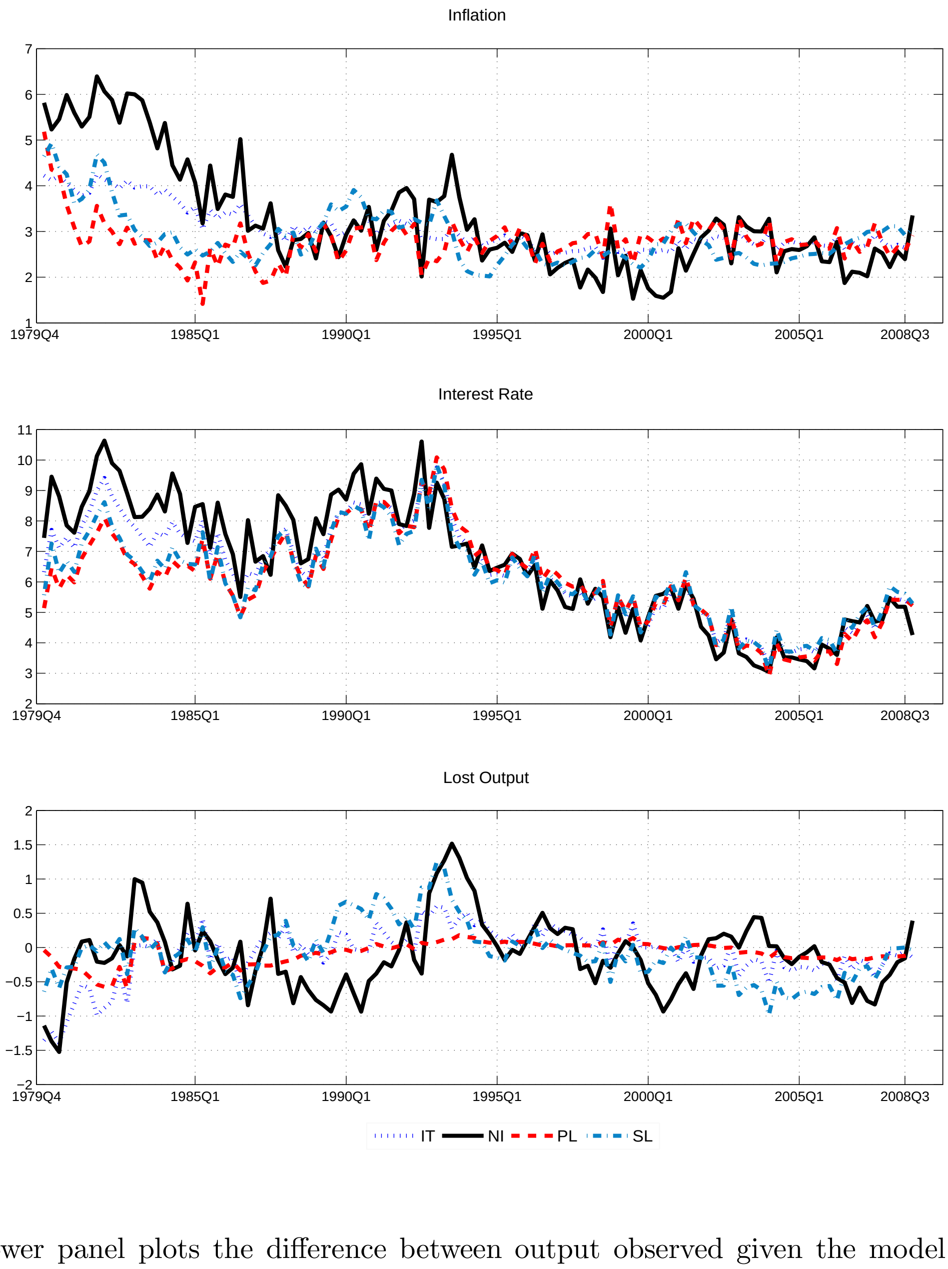
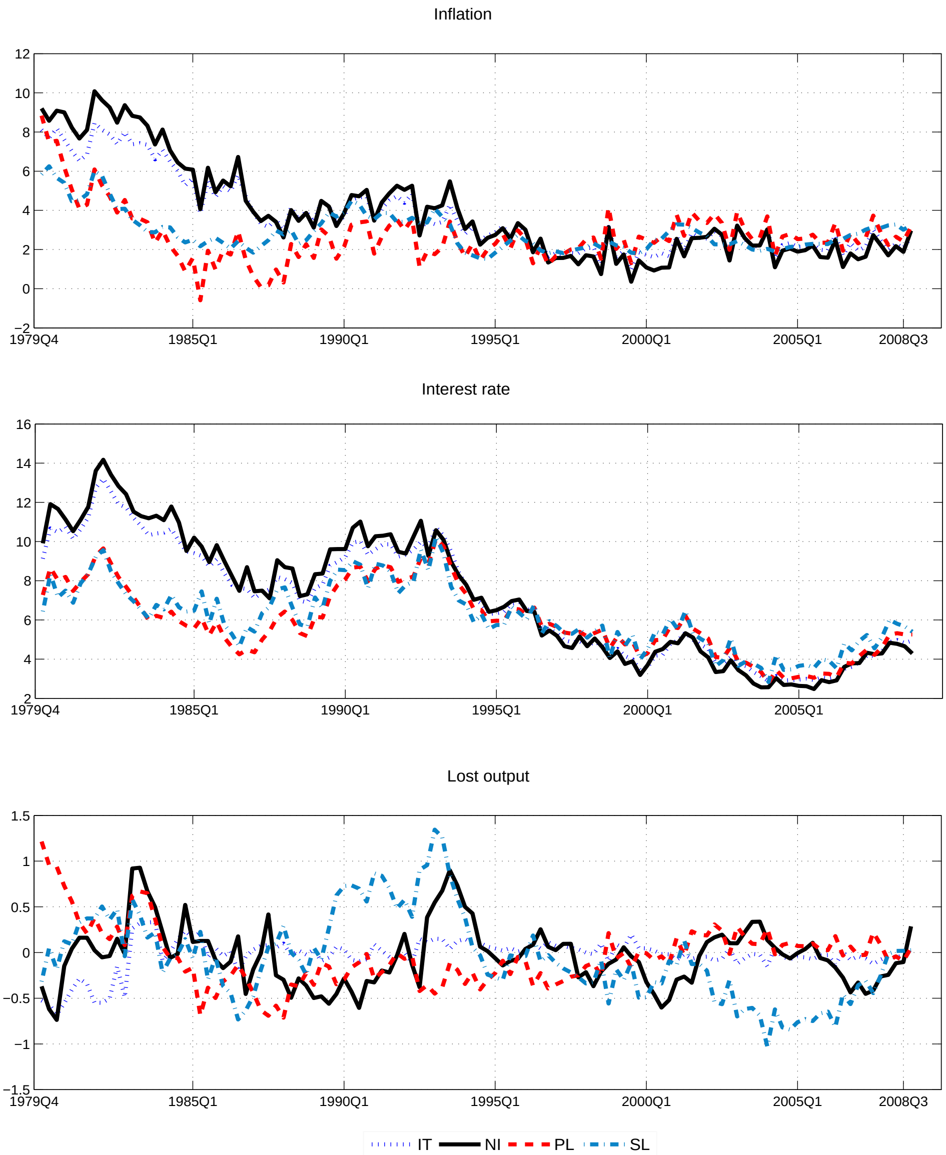


Figure 3: Counterfactuals: Alternative Delegation Schemes (Est. Preferences)



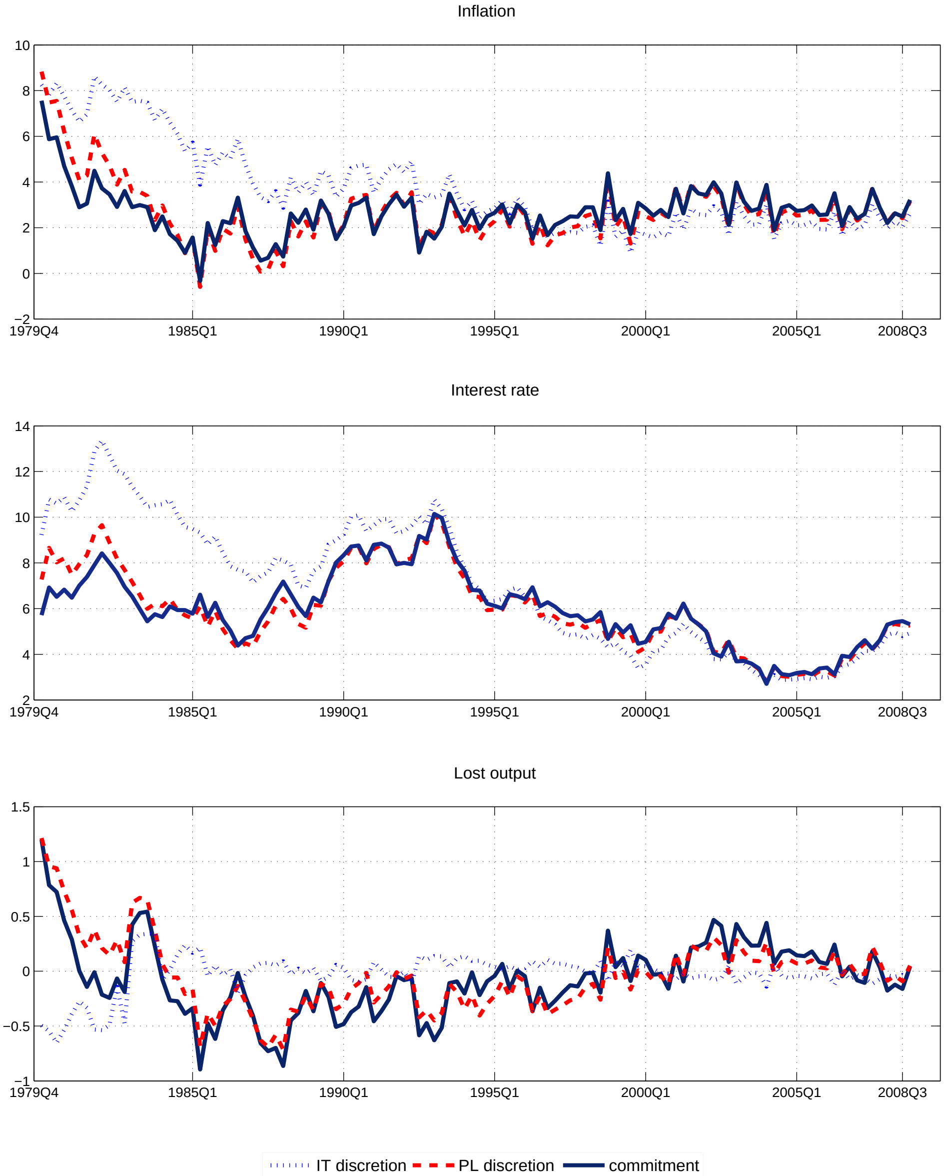
Notes: Lower panel plots the difference between output observed given the model account of regime switches, assuming discretionary policymaking, and output attained if the policy maker follows either optimized inflation, speed limit, nominal income or price level targeting.

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



Notes: Lower panel plots the difference between output observed given the model account of regime switches, assuming discretionary policymaking, and output attained if the policy maker either optimized inflation, speed limit, nominal income or price level targeting.

Figure 5: Counterfactuals: Commitment versus Discretion (Revealed Preferences)



Notes: Lower panel plots the difference between output observed given the model account of regime switches, assuming discretionary policymaking, and output attained if the policy maker is able to act under discretion with $\omega_\pi = 1$, price level target with $\omega_p = 0.018$ and commit *cet. par.*

Figure 6: Policy and Volatility Switches for the extended sample from 1979Q4-2013Q2

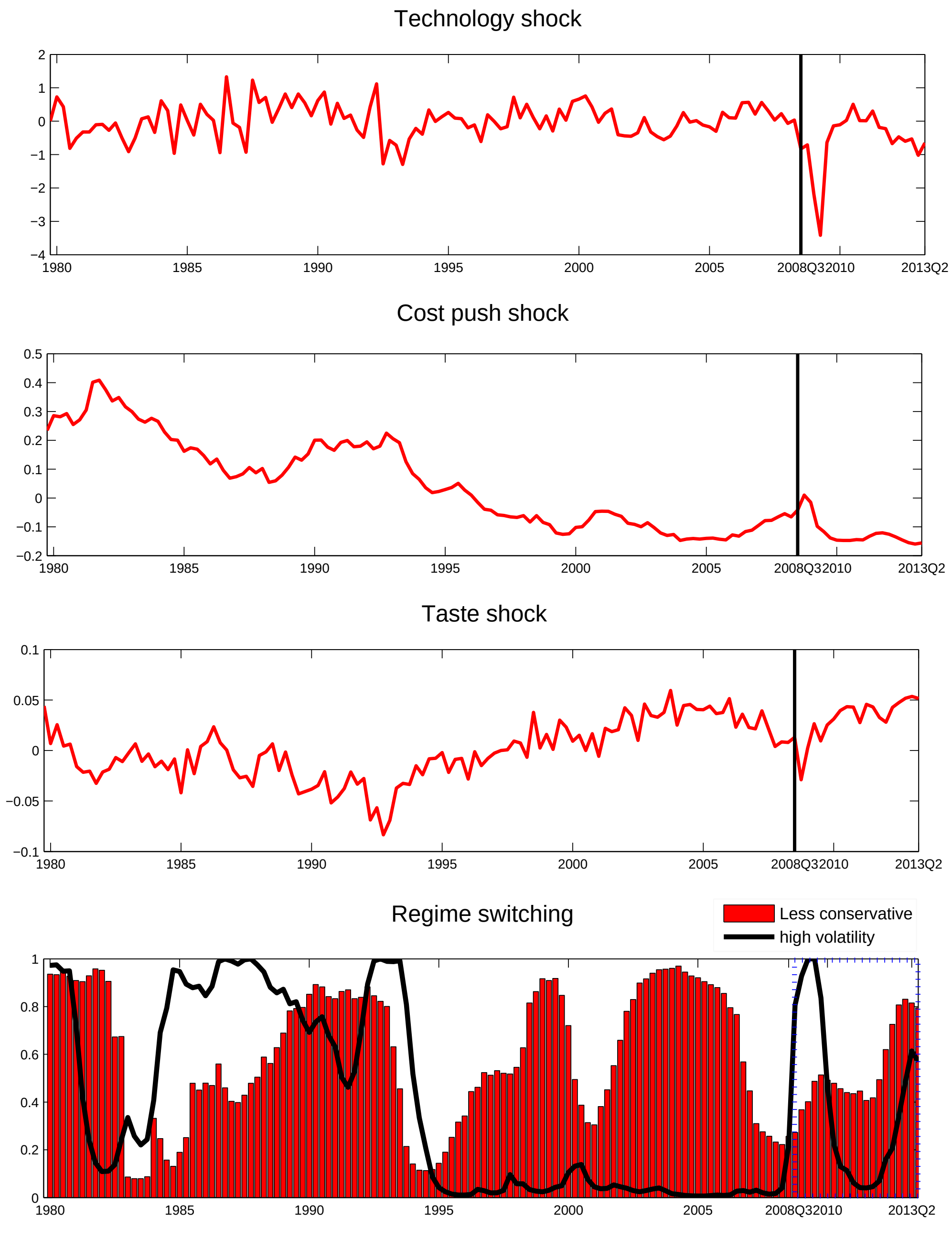


Figure 7: Counterfactuals: Alternative Delegation Schemes

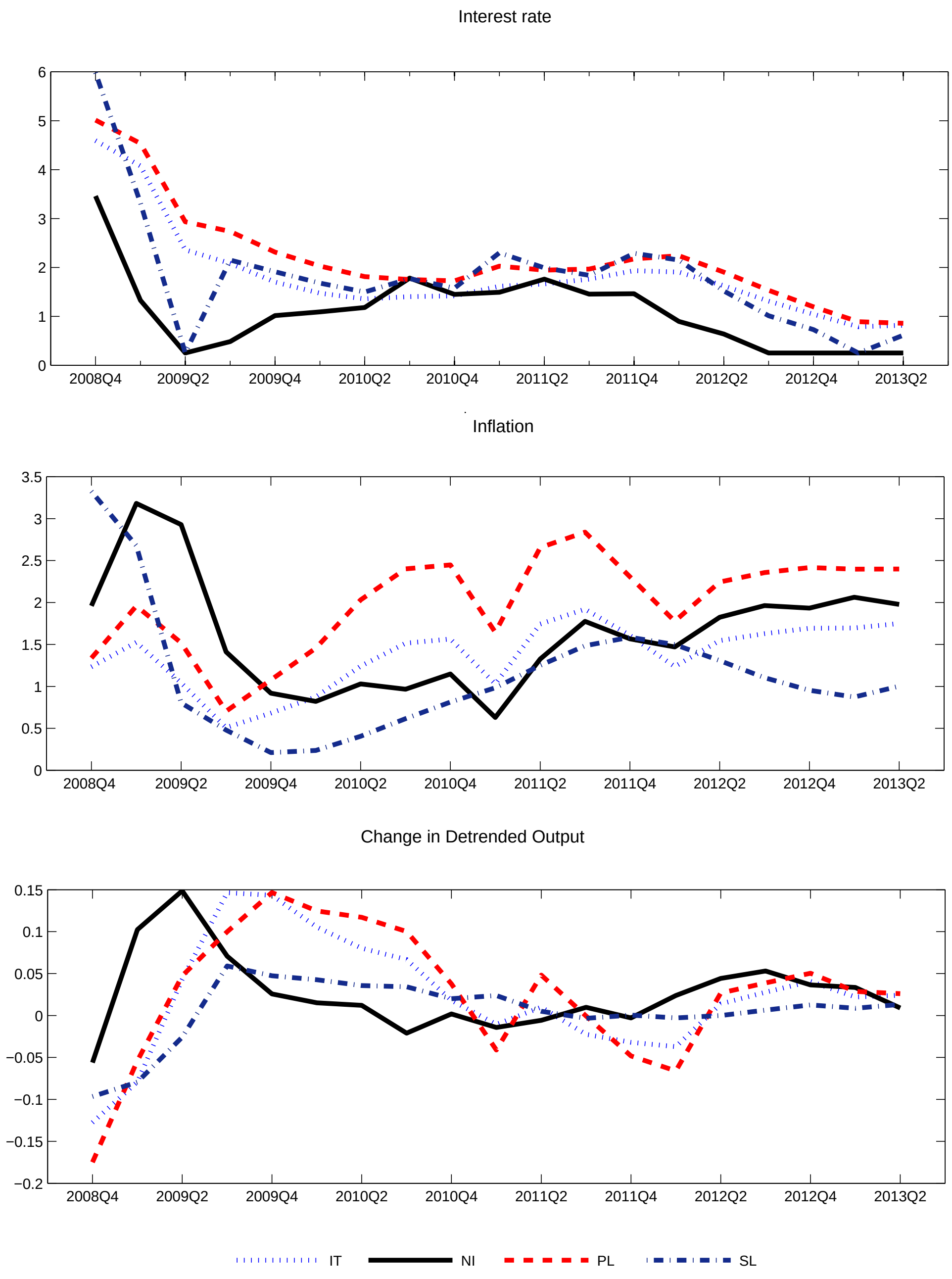


Table 1: Distribution of Priors

Parameters		Range	Density	Mean	Std Dev
Inv. of intertemp. elas. of subst.	σ	$\mathbb{R}$	Nomal	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	$\mathbb{R}$	Nomal	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	$\mathbb{R}$	Nomal	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]
$\sigma^2_{R(s=1)}$	–	0.121 [0.105,0.138]	–	0.125 [0.105,0.145]
$\sigma^2_{R(s=2)}$	–	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 (15). The welfare costs using micro-founded weights is based on equation (13), 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: Optimal Target Weights Across Different Social Welfare Functions

Target		Micro. Weights	Est. Weights	Rev. Pref. Weights
Inflation	ω_π	346.75 [205.4,540.8]	4.93 [4.11,6.22]	1.00 [0.80,1.34]
Nominal Income Growth	ω_{NI}	4.66 [3.13,5.97]	1.66 [1.31,1.95]	0.70 [0.56,0.86]
Speed Limit	ω_{SL}	2.17 [1.14,4.04]	20.15 [11.39,32.70]	55.47 [29.04,99.94]
Price Level	ω_p	370.2 [87.8,2071.5]	0.08 [0.06,0.09]	0.01 [0.01,0.01]

Table 5: Unconditional Variances and Welfare under Alternative Delegation Schemes

Estimated Weights

Target	Output	Inflation	Interest Rate	Welfare Cost (est. weights)
		High Volatility		
Inflation	0.276 [0.177,0.431]	0.048 [0.025,0.075]	0.227 [0.177,0.283]	2.220 [1.121,4.425]
Nominal Income	0.281 [0.183,0.430]	0.255 [0.156,0.367]	0.320 [0.250,0.433]	2.458 [1.394,4.608]
Speed Limit	0.235 [0.139,0.388]	0.027 [0.021,0.035]	0.307 [0.236,0.391]	2.259 [1.158,4.458]
Price Level	0.275 [0.169,0.433]	0.073 [0.048,0.108]	0.421 [0.337,0.569]	2.107 [1.035,4.320]
Commitment	0.298 [0.187,0.454]	0.064 [0.042,0.093]	0.543 [0.426,0.756]	2.094 [1.026,4.309]
		Low Volatility		
Inflation	0.125 [0.085,0.200]	0.029 [0.016,0.046]	0.163 [0.121,0.206]	1.243 [0.616,2.896]
Nominal Income	0.131 [0.091,0.204]	0.146 [0.096,0.205]	0.185 [0.148,0.230]	1.314 [0.670,2.970]
Speed Limit	0.106 [0.068,0.176]	0.013 [0.001,0.016]	0.239 [0.184,0.299]	1.291 [0.642,2.930]
Price Level	0.136 [0.088,0.211]	0.052 [0.034,0.076]	0.344 [0.266,0.423]	1.176 [0.573,2.843]
Commitment	0.152 [0.100,0.223]	0.047 [0.031,0.067]	0.443 [0.339,0.562]	1.170 [0.568,2.836]

Table 6: Unconditional Variances and Welfare under Alternative Delegation Schemes

Revealed Preferences

Policy Target	Output	Inflation	Interest Rate	Welfare Cost (revealed weights)
		High Volatility		
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]
Speed Limit	0.210 [0.119,0.355]	0.073 [0.056,0.095]	0.343 [0.277,0.436]	2.240 [1.135,4.432]
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]
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]
		Low Volatility		
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]
Speed Limit	0.094 [0.058,0.161]	0.034 [0.026,0.043]	0.263 [0.204,0.320]	1.282 [0.635,2.916]
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]
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]

Table 7 :Unconditional Variances and the ZLB under Alternative Delegation Schemes

Historical Data Averages

Policy Target	Output	Inflation	Interest Rate	Welfare Cost (revealed weights)	Fr(R<0)
			High Volatility		
Inflation	0.389	0.687	0.551	2.064	0.000
Nominal Income	0.385	0.808	0.657	2.125	0.005
Speed Limit	0.354	0.262	0.536	2.165	0.001
Price Level	0.433	0.576	0.567	1.929	0.000
			Low Volatility		
Inflation	0.192	0.440	0.255	1.427	0.000
Nominal Income	0.198	0.500	0.296	1.443	0.000
Speed Limit	0.148	0.111	0.431	1.527	0.000
Price Level	0.277	0.426	0.458	1.357	0.000

Table 8 :Unconditional Variances and the ZLB under Alternative Delegation Schemes

The 'New Normal'

Policy Target	Output	Inflation	Interest Rate	Welfare Cost (revealed weights)	Fr(R<0)
			High Volatility		
Inflation	0.389	0.687	0.551	2.064	0.000
Nominal Income	0.368	0.857	0.643	2.126	0.031
Speed Limit	0.353	0.267	0.535	2.167	0.009
Price Level	0.433	0.576	0.567	1.929	0.000
			Low Volatility		
Inflation	0.192	0.440	0.255	1.427	0.000
Nominal Income	0.198	0.500	0.296	1.443	0.000
Speed Limit	0.148	0.111	0.431	1.527	0.000
Price Level	0.277	0.426	0.458	1.357	0.000