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

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Abstract

We estimate a New Keynesian DSGE model for the Euro area which allows for alternative descriptions of monetary policy (discretion, commitment, quasi-commitment or a simple rule) after allowing for Markov switching in policy maker preferences and/or shock volatilities. This reveals that there have been several changes in Euro area policy making, with a strengthening of the anti-inflation stance in the early years of the ERM, which was then lost around the time of German reunification and only recovered following the turmoil in the ERM in 1992. The ECB does not appear to have been as conservative as aggregate Euro-area policy was under Budesbank leadership. The estimates 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. Finally, 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.

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

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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 this extent to which this was simply was ‘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) typically associated with the Volcker disinflation which tends to be dated as occurring in 1979.

Chen, Kirsanova, and Leith (2013) contribute to this debate by allowing the policy maker to implement an optimal policy rather than the ad hoc simple rules typically assumed. Specifically, they allow policy to be either operate under discretion (time-consistent), commitment (time-inconsistent) or an intermediate case, called variously, quasi- (Schaumburg and Tambalotti, 2007), loose- (Debertoli and Nunes, 2010) or limited- (Himmels and Kirsanova, 2013) commitment. Estimating a simple New Keynesian DSGE model which embeds these alternative policy descriptions, they find that the US Fed’s behavior is best described as being consistent with optimal discretionary policy, with switches in the degree of Fed conservatism. This description dominates all other forms of optimal policy and that of simple rules, even after allowing for switches in rule parameters and/or the inflation target and also allowing for switches in shock volatilities. Moreover, the switches in policy maker preferences reveal not only the move to greater monetary policy conservatism associated with the Volcker disinflation (although occurring slightly later in early 1982, rather than the earlier date usually associated with switches in rule-based estimates), but also that there was a temporary loss in conservatism following the stock market crash of 1987 and a more prolonged relaxation of policy following the bursting of the dot-com bubble in 2000, which lasted until the financial crisis. These subtle policy shifts are not so easily discerned from estimates based on ad hoc simple rules. The estimates also suggest that while good luck is more important than good policy in explaining the Great Moderation in the US, an ability to commit would have lead to far greater welfare gains even without any other changes in luck or policy.

In this paper we perform a similar analysis for the Euro area. This is important as 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-zone monetary authority in the shape of the European Central Bank 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, and although there were several exchange rate realignments within the ERM in the early years, (see Ozkan, 2003, for a detailed list of these realignments and estimates of their fundamental causes) 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). However, even given its leadership role within the ERM, German monetary policy 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 order to explore the changes in Euro-area policy making, we shall estimate a simple New Keynesian model, under the alternative descriptions of optimal and rule-based policy listed above and allowing for switches in policy maker preferences (or rule parameters/inflation targets when policy is described by a 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 find that there have been several switches in the conservatism of Euro-area monetary policy, with the first move to a more conservative regime occurring a couple of years after the creation of the ERM. However, this conservatism was gradually lost in the second half of the 1980s, with a peak relaxation in the anti-inflation stance of the policy associated with German reunification in 1990, contradicting the criticisms of Bundesbank policy as being excessively tight as a response to internal concerns rather than the needs of the ERM economies more broadly. Conservatism was then regained shortly after the tensions in the ERM emerged in September 1992. Interestingly, it was then relaxed in the late 1990s prior to the creation of the Euro, and for much of the first decade of the Euro’s existence. These subtle shifts in policy making are not so readily captured when policy is described by switches in a simple ad hoc policy rule.
We then utilize these estimates to undertake various counterfactual analyses of Euro-area policy making. Firstly, we consider the European ‘Great Moderation’, and assess the relative contributions of ‘good luck’ and ‘good policy’ to that moderation. While both elements can half the volatility of inflation, the major welfare improvement comes from the reduction in shock volatility since this reduces output volatilities in a way that greater conservatism does not. Secondly, we assess the gains to commitment, and find these to be substantial relative to either good luck or increased conservatism. Thirdly, we undertake an assessment of alternative delegation schemes (flexible inflation targets, price level targets, speed limit policies and nominal income growth targets) for the Euro-area as a means of bringing policy outcomes closer to those observed under commitment. In doing so we consider alternative approaches to measuring social welfare prior to designing the various delegation schemes - specifically we consider a micro-founded measure of social welfare, a similar measure but where the weights are freely obtained as part of the estimation and a ‘revealed preference’ measure where the conservatism of society is inferred by observing the preferences of the policy maker society chooses to appoint, in a reverse engineering application of Rogoff (1985)’s conservative central banker. This analysis suggests that (flexible) price level targeting yields the greatest benefits and would have done so in the 1970s, as well as the 1990s. Finally, we consider the more recent policy experience and seek to identify the shocks which placed the ECB at the ZLB, and the extent to which forward guidance can augment discretionary policy making in such a situation [This final section is incomplete].

Chen et al. (2013) discuss in detail the large literature relating to the estimation of DSGE models for policy analysis, along with the associated assessment of the causes of the Great Moderation which rely on some combination of shifts in policy and/or shifts in the volatility of shocks hitting the economy. As noted above, the vast majority of this literature is concerned with the US economy and shifts in US Fed policy and relatively few studies consider the Euro-area economy. Notable exceptions include 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, but there are sizeable changes in the volatilities of structural shocks (although not monetary policy 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 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 et al. (2005) find, using a Markov switching Structural VAR, that the Great Moderation in the Euro-area is largely due to a reduction in shock volatilities. Other studies, starting with Clarida, Galí, and Gertler (1998), consider German monetary policy in isolation and 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 model of the Euro-area which allows for the wide range of descriptions of policy we consider in conjunction with the shifts in policy and/or 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 Bayesian estimation of our model in Section 4, and describe the data and priors in Section 5, before presenting our estimation results in Section 6. Section 7 then undertakes various counterfactual simulation exercises which enable us to explore both the sources and welfare consequences of the ‘Great Moderation’, but also assess the potential benefits of further improvements in the conduct of monetary policy. Section 8 considers the ability of alternative delegation schemes to achieve welfare levels approaching those under commitment. The impact of the ZLB on our delegation schemes is considered in Section 9. We then reach our conclusions in Section 10.
2 The Model

The model is the same as that in Chen et al. (2013). The economy is comprised of households, a monopolistically competitive production sector, and the government. There is a continuum of goods that enter the households’ consumption basket. Households form external consumption habits at the level of the consumption basket as a whole - ‘superficial’ habits.\(^1\) Furthermore, we assume the economy is subject to both price and inflation inertia. Both effects have been found to be important in capturing the hump-shaped responses of output and inflation to shocks evident in VAR-based studies, and are often employed in empirical applications of the New Keynesian model.\(^2\)

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, 
\[
U_k = \left( \int_0^1 \left( C_k^t \right)^{\frac{\eta - 1}{\eta}} \mathrm{d}t \right)^{\frac{1}{\eta - 1}}
\]
where \(\eta\) is the elasticity of substitution between the goods in this basket and suffer disutility from hours spent working, \(N_k^t\). 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,
\[
U_k = \beta^t \left[ \frac{(C_k^t/A_t - \theta C_{t-1}/A_{t-1})^{1-\sigma} (\xi_t)^{-\sigma}}{1 - \sigma} - \frac{(N_k^t)^{1+\varphi} (\xi_t)^{-\sigma}}{1 + \varphi} \right]
\]
where \(C_{t-1} \equiv \int_0^1 C_{t-1}^k \mathrm{d}k\) is the cross-sectional average of consumption.\(^3\) In other words households gain utility from consuming more than other households, and are disappointed if their

\(^1\)For a comparison of the implications for optimal policy of alternative forms of habits see Leith et al. (2012).
\(^3\)Note that this utility specification is slightly different from that in Lubik and Schorfheide (2005) who adopt the following specification, \((C_t - \theta C_{t-1}/A_t)^{1-\sigma} (\xi_t)^{-\sigma}/(1-\sigma)\). Their specification introduces a technology shock into the definition of habits adjusted consumption which then complicates the derivation of welfare. Therefore we adopt a specification which implies habits in detrended variables, which means that the only place the technology shock appears is in the consumption Euler equation.
consumption doesn’t grow in line with technical progress and are subject to a time-preference or taste-shock, $\xi_t$. $\mathbb{E}_t$ is the mathematical expectation conditional on information available at time $t$, $\beta$ is the discount factor ($0 < \beta < 1$), and $\sigma$ and $\varphi$ are the inverses of the intertemporal elasticities of habit-adjusted consumption and work ($\sigma, \varphi > 0$; $\sigma \neq 1$).

The process for technology is non-stationary,

$$\ln A_t = \ln \gamma + \ln A_{t-1} + \ln \tilde{z}_t$$
$$\ln \tilde{z}_t = \rho \ln z_{t-1} + \varepsilon_{z,t}$$

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

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

**Remainder of the Household’s Problem** The remainder of the household’s problem is standard. Specifically, 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

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

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, $\tau_t$, dividends from the monopolistically competitive firms, $\Phi_t$, 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, $\tau_t$, 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. Finally there is an autocorrelated preference shock, $\xi_t$.

In the maximization problem, households take as given the processes for $C_t^{1}, W_t, \Phi_t,$ and $T_t$, as well as the initial asset position $D^{k}_{1}$. The first order conditions for labor and habit-adjusted consumption are

$$\frac{(N_t^{k})^{\phi}}{(X_t^{k})^{\sigma}} = \frac{W_t}{P_tA_t} (1 - \tau_t)$$

and

$$Q_{t,t+1} = \beta \left( \frac{X_{t+1}^{k+1} \xi_{t+1}^{t}}{X_{t+1}^{k} \xi_{t+1}^{t}} \right)^{-\sigma} \frac{A_t}{A_{t+1}} \frac{P_t}{P_{t+1}}.$$

Taking expectations, the Euler equation for consumption can be written as

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

where $R_t^{-1} = E_t [Q_{t,t+1}]$ 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 $\alpha$ 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, $E_t \sum_{s=0}^{\infty} \alpha^s Q_{t,t+s} \Phi_{it+s}$, 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 (1) 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.

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

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

where $Q_{t,t+s} = \beta^s \left( \frac{X_{t+1}^{k+1} \xi_{t+1}^{t}}{X_{t+1}^{k} \xi_{t+1}^{t}} \right)^{-\sigma} \frac{P_t}{P_{t+s}}.$
The relative price set by firms able to reset prices optimally in a forward-looking manner, satisfies the following relationship

\[
\frac{P_f}{P_t} = \frac{\eta}{\eta-1} \sum_{s=0}^{\infty} \left( (\alpha \beta)^s \left( X_{t+s} \xi_{t+s} \right)^{-\sigma} mc_{t+s} \left( \frac{P_{t+s}}{P_t} \right)^{\eta} \frac{Y_{t+s}}{A_{t+s}} \right),
\]

where \( mc_t = MC_t / P_t \) is the real marginal cost and \( P_f \) 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 (2), a proportion of those firms, \( \zeta \), follow a simple rule of thumb in resetting that price

\[
P^b_t = P^*_{t-1} \pi_{t-1},
\]

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

\[
\ln P^*_{t-1} = (1 - \zeta) \ln P^f_{t-1} + \zeta P^b_{t-1}.
\]

\( P_t \) represents the price level at time \( t \). With \( \alpha \) 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,

\[
(P_t)^{1-\eta} = \alpha (P_{t-1}^{*\pi})^{1-\eta} + (1 - \alpha) (P_t^*)^{1-\eta}.
\]

Denoting the fixed share of price-setters following the rule of thumb (3) by \( \zeta \), 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

\[
\tilde{\pi}_t = \chi_f \beta \tilde{\pi}_{t+1} + \chi_b \tilde{\pi}_{t-1} + \kappa_c (\tilde{mc}_t),
\]

where \( \tilde{\pi}_t = \ln(P_t) - \ln(P_{t-1}) - \ln(\pi) \) is the deviation of inflation from its steady state value, \( \tilde{mc}_t = \ln(W_t/P_t) - \ln A_t - \ln((\eta - 1)/\eta) \), 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 Appendix 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. Log-linearizing the equilibrium conditions (36) - (49) around the deterministic steady state detailed in the Appendix, gives the following set of equations:

\[
\sigma \hat{X}_t + \varphi \hat{N}_t = \hat{w}_t - \hat{\mu}_t \quad \text{Labor Supply} \quad (4)
\]

\[
\hat{X}_t = E_t \hat{X}_{t+1} - \frac{1}{\sigma} \left( \hat{R}_t - E_t \hat{\pi}_{t+1} - E_t \hat{z}_{t+1} \right) - \hat{\xi}_t + E_t \hat{\xi}_{t+1} \quad \text{Euler Equation} \quad (5)
\]

\[
\hat{y}_t = \hat{N}_t = \hat{c}_t \quad \text{Resource Constraint} \quad (6)
\]

\[
\hat{X}_t = (1 - \theta)^{-1} (\hat{c}_t - \theta \hat{c}_{t-1}) \quad \text{Habits-Adjusted Consumption} \quad (7)
\]

\[
\hat{\pi}_t = \chi_f \beta E_t \hat{\pi}_{t+1} + \chi_0 \hat{\pi}_{t-1} + \kappa_c (\hat{w}_t), \quad \text{Hybrid NKPC} \quad (8)
\]

\[
\hat{z}_t = \rho^z \hat{z}_{t-1} + \varepsilon_{z,t} \quad \text{Technology Shock} \quad (9)
\]

\[
\hat{\mu}_t = \rho^\mu \hat{\mu}_{t-1} + \varepsilon_t^\mu \quad \text{Cost-Push Shock} \quad (10)
\]

\[
\hat{\xi}_t = \rho^\xi \hat{\xi}_{t-1} + \varepsilon_t^\xi \quad \text{Preference Shock} \quad (11)
\]

where \( \hat{\mu}_t = \tau \hat{\pi}_t / (1 - \tau) \) 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. Appendix C derives an objective function based on the utility of the households populating the economy as

\[
L = -\frac{1}{2} N^{1+\phi} \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left\{ \frac{\sigma(1-\theta)}{1-\beta} \left( \hat{X}_t + \hat{\xi}_t \right)^2 + \varphi \left( \hat{y}_t - \frac{\sigma}{\varphi} \hat{\xi}_t \right)^2 \right\} + tip + O[2] \tag{12}
\]

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 differs from that of the representative household. Below, we shall contrast these estimated objective function weights with those of the representative household, 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’ - to design optimal delegations schemes for the Euro-area economy.

3 Policy

We consider four basic forms of policy, a simple rule and three types of optimal policy (discretion, commitment and quasi-commitment), 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 under optimal policy.
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),

$$R_t = \rho^R R_{t-1} + (1 - \rho^R) [\psi_1 \hat{\pi}_t + \psi_2 (\Delta \hat{y}_t + \hat{z}_t)]$$ (13)

where the monetary policy maker adjusts interest rates in response to movements in inflation and deviations of output growth from trend.\(^4\) In model estimations which assume policy is described by a simple rule without any switches in rule parameters it is typical to assume that \(\psi_1, \psi_2 \geq 0\), such that the rule is determinate, and that the smoothing term in the rule is: \(0 \leq \rho^R < 1\). Subsequently, equations (4)-(11) and (13) can be written as a linear rational expectation system of the form

$$\Gamma_0 X_t = \Gamma_1 X_{t-1} + \Psi Z_t + \Pi \eta_t$$ (14)

where \(X_t = [\tilde{z}_t, \tilde{\mu}_t, \tilde{\xi}_t, \hat{\pi}_t, \hat{\beta}_t, \hat{R}_t, \hat{E}_t \hat{y}_{t+1}, \hat{E}_t \hat{z}_{t+1}]\)' is a vector of eight state variables, which includes six predetermined variables and two non-predetermined, or jump, variables. Vector \(Z_t\) stacks the exogenous shocks and \(\eta_t\) is composed of rational expectation forecast errors. \(\Gamma_0, \Gamma_1, \Psi\) and \(\Pi\) are matrices containing structural parameters. A standard solution technique, such as Sims (2002), can be used to solve the linear rational expectation system in equation (14). It returns a solution as a reduced AR(1) process.

$$X_t = \Phi_1 X_{t-1} + \Phi_2 Z_t, \ Z_t \sim NID(0, \Sigma)$$

Within this framework of a generalized Taylor rule, we account for potential changes in Euro-area monetary policy by allowing for either changes in the policy maker’s inflation target or rule parameters. In the former case the measure of excess inflation in the Taylor rule, \(\bar{\pi}_t\), involves removing the inflation target from the data, where, following Schorfheide (2005), we allow that inflation target to follow a two-state Markov-switching process. Modelling monetary policy changes as movements in the inflation target are not computationally demanding as Sims (2002) algorithm can still be employed to solve this model.\(^5\)

However, when the policy changes are described as shifts in rule parameters \((\rho^R, \psi_1, \psi_2)\) between two regimes, standard solution techniques are no longer applicable. Therefore, Svensson and Williams (2007), Davig and Leeper (2007) and Farmer, Waggoner, and Zha (2008, 2009, 2011)

\(^4\)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).

\(^5\)The details of this model can be found in Schorfheide (2005).
all provide algorithms to solve DSGE models with Markov-switches in structural parameters.\footnote{Chen and MacDonald (2012) provide a discussion of these algorithms.} In this paper, we adopt the procedure developed by Farmer et al. (2008) to solve the model with Markov-switching in simple rule parameters. This model can be recast in the following system

\[
\Gamma_0(S_t = j)X_t = \Gamma_1(S_t = j)X_{t-1} + \Psi(S_t = j)Z_t + \Pi(S_t = j)\eta_t. \tag{15}
\]

Compared to the time-invariant interest rate rule contained in equation (14), $\Gamma_0, \Gamma_1, \Psi$ and $\Pi$ in (15) depend on an unobserved state variable, $S_t = j$, for $j \in \{1, 2\}$, that follows a two-state Markov process with transition probabilities

\[
\Pr[S_t = 1|S_{t-1} = 1] = p_{11}, \Pr[S_t = 2|S_{t-1} = 2] = p_{22}.
\]

Following Farmer et al. (2008), equation (15) can be rewritten as the following model with regime-invariant parameters

\[
\Gamma_0X_t = \Gamma_1X_{t-1} + \Psi Z_t + \Pi \eta_t, \tag{16}
\]

where $\Gamma_0, \Gamma_1, \Psi$ and $\Pi$ are matrices that are functions of structural parameters and transition probabilities. Farmer et al. (2008) define a Minimum State Variable (MSV) solution to equation (16) and prove that it is also a solution to the original MSRE model specified in equation (15). Provided a unique solution exists, equation (16) can be written as an AR(1) process with Markov-switching parameters

\[
X_t = \Phi_1(S_t = j)X_{t-1} + \Phi_2(S_t = j)Z_t, Z_t \sim NID(0, \Sigma).
\]

It is important to note that the estimated rule in a particular state need not satisfy the Taylor principle, $\psi_1 > 1$, and that this need not imply indeterminacy provided the rule in alternative states is sufficiently responsive to inflation. This ‘spillover’ from one regime to another reflects the fact that economic agents are assumed to anticipate the Markov switching between different policy rules.

In addition to incorporating monetary policy changes, we also account for the ‘good luck’ factor that is normally modelled as a decrease in the volatility of shocks hitting the economy. Therefore, we allow for independent regime switching in the variances, $\Sigma$, of three shocks (i.e. $\sigma_z, \sigma_\mu, \text{and } \sigma_\zeta$) that depends on the unobserved state variable, $s_t = i$, for $i \in \{1, 2\}$, and has the transition probabilities:

\[
\Pr[s_t = 1|s_{t-1} = 1] = q_{11}, \Pr[s_t = 2|s_{t-1} = 2] = q_{22}
\]

This results in a four-state transition matrix and $4^2 = 16$ states are carried at each iteration.
3.2 Optimal Monetary Policy

We now turn to describe our optimal monetary policy specifications. Relative to the number of models estimated with various simple rules, the empirical studies based on optimal policies are few, and tend to only focus on optimal policies under two polar extremes: full commitment or discretion. As with these studies (i.e. Givens, 2012; Le Roux and Kirsanova, 2013), we performed an empirical estimation based on optimal policies derived under either full commitment or discretion, but we also considered the intermediate case of quasi-commitment. To compute optimal policies, we recast the set of log-linearized equations in (4)-(11) the following state-space form

$$X_{t+1} = AX_t + Bi_t + C_0 \varepsilon_{t+1},$$

(17)

where $X_t = [\xi_t, \tilde{\pi}_t, \tilde{y}_t, \tilde{\pi}_{t-1}, \tilde{R}_{t-1}]'$ is a vector of predetermined variables; $x_t = [\tilde{y}_t, \tilde{\pi}_t]'$ is a vector of forward-looking variables; $i_t = [\tilde{R}_t]$ is the control variable, and $\varepsilon_t = [\varepsilon^*_t, \varepsilon^i_t, \varepsilon^2_t]$ contains a vector of zero mean i.i.d. shocks. Without loss of generality, the shocks are normalized so that the covariance matrix of $\varepsilon_t$ is $I$. Therefore, the covariance matrix of the shocks to $X_{t+1}$ is $CC'$. $A$ and $B$ are matrices containing the model’s structural parameters. The central bank selects interest rates to maximize objective (12) subject to (17). We use the procedure described by Söderlind (1999) to solve for the equilibrium dynamics under both commitment and discretion.

However, estimation with micro-founded weights is problematic. Since the micro-founded weights are functions of structural parameters, they place very tight cross-equation restrictions on the model which are generally thought to be implausible. In particular, for standard estimates of the degree of price stickiness, the micro-founded weight attached to inflation can be over 100 times that attached to the output terms (see Woodford, 2003, Ch.6). Optimal policies which were based on such a strong anti-inflation objective would clearly be inconsistent with observed inflation volatility (we explore this issue further in Section 8). Therefore, for estimation, we adopt a form of the objective function which is consistent with the representative agents’ utility, but allow the weights within that objective function in (12) to be freely estimated, and the resulting objective function is given by

$$\Gamma = -N^{1+\varphi} \frac{1}{2} \sum_{t=0}^{\infty} \beta^t \left\{ \omega_1 \left( \tilde{X}_t + \tilde{\xi}_t \right)^2 + \omega_2 \left( \tilde{y}_t - \frac{\sigma}{\varphi} \tilde{\xi}_t \right)^2 + \omega_\pi (\tilde{\pi}_t^2 + \frac{\zeta \alpha^{-1}}{1-\zeta} (\tilde{\pi}_t - \tilde{\pi}_{t-1})^2) \right\},$$

(18)

where the weight on inflation, $\omega_\pi$, is normalized to 1. It is important to note that we do not augment our objective function with any ad hoc terms, such as a desire for interest rate smoothing, that are not implied by the underlying model. 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.

Under full commitment, the central bank chooses a contingent interest rate plan for all future dates. When optimizing, the central bank internalizes the impact of its policies on the private sector’s expectations. By being able to influence expectations through future policy commitments the policy maker can obtain a more favorable trade-off between the stabilization of inflation and output. The solution to the commitment problem is as follows

\[
\begin{align*}
\begin{bmatrix}
X_{t+1} \\
\psi_{t+1}
\end{bmatrix} &= M_c \begin{bmatrix}
X_t \\
\psi_t
\end{bmatrix} + \begin{bmatrix}
C \\
0
\end{bmatrix} \varepsilon_{t+1} \\
\begin{bmatrix}
x_t \\
i_t
\end{bmatrix} &= G_c \begin{bmatrix}
X_t \\
\psi_t
\end{bmatrix},
\end{align*}
\]

where \( \psi_t \) is a vector of Lagrangian multipliers associated with forward-looking variables. The fact that the choice of interest rates depends on \( \psi_t \) implies that the central bank is assumed, under commitment, to honor past promises.

In contrast, under discretion, the central bank is not bound by its past promises. Therefore, in each period, it evaluates the current state of the economy and formulates the optimal policy. The policy outcome under discretion is only optimal in a constrained sense because the central bank can neither control the private sector’s expectations by making promises about the policies that will be implemented in the future, nor coordinate with future policy makers.\(^7\) Therefore, policy only depends on the current state

\[
\begin{align*}
X_{t+1} &= M_d X_t + C \varepsilon_{t+1} \\
\begin{bmatrix}
x_t \\
i_t
\end{bmatrix} &= G_d X_t. 
\end{align*}
\]

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 realize that both commitment and discretion policies derived under an assumption of unchanging policy maker preferences may be too stylized to capture such changes. Therefore, in our empirical analysis we attempt to relax the assumption of a time-invariant objective function that is used to derive optimal policies under both commitment and discretion. To do so, we adopt the algorithm developed by Svensson and Williams (2007) that solves optimal monetary policies in Markov jump-linear-quadratic systems. This algorithm can incorporate structural changes in both the model (17) and weights in the objective function.

\(^7\)In our model with endogenous state variables, due to habits formation and inflation inertia, current policies will influence future expectations through their impact on the states bequeathed to the future. However, crucially, under discretion the policy maker cannot make any additional commitments in the hope of favorably influencing expectations.
function (18). However, in this paper, we only focus on potential changes in the Euro-area monetary policy objective on inflation targeting. Specifically, we allow the weight on inflation, $\omega_\pi$, to be subject to regime shifting between 1 and a value lower than 1. By doing so, we can identify whether there are periods where Euro-area has adopted different attitudes towards inflation at different points in 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.

Furthermore, we also consider 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 follow 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). The optimization problem under

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8The 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.
quasi-commitment can be expressed by the following Lagrangian:

\[
\min \mathbb{E}_0 \sum_{t=0}^{\infty} ((1 - v) \beta)^t \left\{ \frac{\omega_1}{2} \left( \tilde{X}_t + \tilde{\xi}_t \right)^2 + \omega_2 \left( \tilde{y}_t - \tilde{\xi}_t \right)^2 + \omega_3 \left( \tilde{b}_t - \tilde{\xi}_t \right)^2 + \omega_4 \left( \tilde{c}_t - \tilde{\xi}_t \right)^2 \right\}
\]

subject to

\[
\begin{bmatrix}
X_{t+1} \\
\psi_{t+1}
\end{bmatrix} = A \begin{bmatrix} X_t \\ \psi_t \end{bmatrix} + B \varepsilon_t + \begin{bmatrix} C \\ 0 \end{bmatrix} \varepsilon_{t+1}
\]

where \(0 \leq v \leq 1\) is the probability that the monetary authority reneges on the past policy promises at each period. The solution to the quasi-commitment problem is given by

\[
\begin{bmatrix}
X_{t+1} \\
\psi_{t+1}
\end{bmatrix} = M_{qc} \begin{bmatrix} X_t \\ \psi_t \end{bmatrix} + \begin{bmatrix} C \varepsilon_{t+1} \\ 0 \end{bmatrix}
\]

\[
\begin{bmatrix}
X_t \\
\psi_t
\end{bmatrix} = G_{qc} \begin{bmatrix} X_t \\ \psi_t \end{bmatrix},
\]

where \(M_{qc}\) and \(G_{qc}\) are partitioned with \(X_t\) and \(\psi_t\) as follows

\[
M_{qc} = \begin{bmatrix} M_{XX} & M_{X\psi} \\ M_{\psi X} & M_{\psi\psi} \end{bmatrix}, \quad G_{qc} = \begin{bmatrix} G_{xx} & G_{x\psi} \\ G_{\psi x} & G_{\psi\psi} \end{bmatrix}.
\]

If \(v = 1\), the monetary authority re-optimizes its policy every period and the resulting transition matrix is equivalent to the optimal policy under discretion as in (19). On the contrary, if \(v = 0\), the monetary authority will keep its promises and this is essentially a policy problem with full commitment. In general, a value of \(v\) close to 1 implies that the policy maker is forced to take inflationary expectations as under the discretionary policy problem, while \(v\) close to zero means that she can make (partial) promises over future policy actions which have a beneficial impact on expectations, as under commitment.

The solutions of the quasi-commitment problem can be easily combined with a two-state Markov-switching model to identify the periods in which the policy maker reneges on previous plans before embarking on a new quasi-commitment policy, such that

\[
M_{qc} = \begin{bmatrix} M_{XX} & M_{X\psi} (S_t = j) \\ M_{\psi X} (S_t = j) & M_{\psi\psi} (S_t = j) \end{bmatrix}, \quad G_{qc} = \begin{bmatrix} G_{xx} & G_{x\psi} (S_t = j) \\ G_{\psi x} & G_{\psi\psi} (S_t = j) \end{bmatrix}
\]

where the unobserved state variable, \(S_t\), follows a two-state Markov process with transition probabilities

\[
\Pr[S_t = 1|S_{t-1} = 1] = (1 - v), \quad \Pr[S_t = 2|S_{t-1} = 2] = v.
\]
If $S_t = 2$, elements in matrices $M_{x\psi}, M_{x\psi}, M_{x\psi}, G_{x\psi}$ and $G_{i\psi}$ reflecting the Lagrange multipliers associated with forward-looking variables switch to zero indicating that the monetary policy authority breaks its promises.

Finally, as with the model with the simple rules, we allow for independent regime switching in variances of shocks under optimal policy, i.e. $\sigma_z, \sigma_\mu$, and $\sigma_\zeta$. 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.

Therefore, to summarize, we consider four basic forms of policy: simple rules, commitment, discretion and quasi-commitment. 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 Strategy

For estimation, the recursive equations derived under simple rule and optimal policy are linked to the observed variables through a measurement equation specified as:

$$
\begin{bmatrix}
  \Delta GDP_t \\
  INF_t \\
  INT_t
\end{bmatrix}
= 
\begin{bmatrix}
  \gamma Q + \Delta \eta_t + \xi_t \\
  \pi A + 4 \bar{\pi}_t \\
  r^A + A^4 + 4 \gamma Q + 4 \bar{R}_t
\end{bmatrix}
$$

The observed variables are quarterly output growth ($\Delta GDP_t$), annualized domestic inflation ($INF_t$) and the nominal interest rate ($INT_t$). The parameters, $\gamma Q$, $\pi A$ 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, $\pi A$ is weighted average of a high $\pi H$ and low $\pi L$ inflation targets. For the other models, we also experiment by incorporating an independent Markov chain to investigate potential switching in $\pi A$ over the sample period. This switch is only supported by the data under commitment which therefore retains this additional element.
For the other models, other than commitment, \(\gamma^Q, \pi^A\) and \(r^A\) remain time-invariant. In the case of commitment, we found that estimates were sensitive to the prior for the steady-state rate of inflation when we imposed that the steady-state was time-invariant. We therefore, when estimating the model under commitment, allow the steady-state of inflation to follow a two-state Markov process, which produces a more robust set of estimates and is preferred by the data. Similar switches in the mean of inflation are not data-preferred for the other descriptions of policy and we therefore only report estimates for these models using time-invariant inflation means. These parameters will all be estimated as part of the model estimation.

We adopt the Bayesian approach in estimating all our models. For models with Markov-switching parameters, the posterior distribution is obtained through Bayes theorem

\[
p(\theta, \phi, S^T|Y^T) = \frac{p(Y^T|\theta, \phi, S^T)p(S^T|\phi)p(\phi, \theta)}{\int p(Y^T|\theta, \phi, S^T)p(S^T|\phi)p(\phi, \theta) d(\theta, \phi, S^T)}
\]

(20)

where \(p(\phi, \theta)\) is the prior for the structural parameters, \(\theta\), and the transition probabilities, \(\phi\). \(p(S^T|\phi)\) is the prior for the unobserved states and \(p(Y^T|\theta, \phi, S^T)\) is the likelihood function. Since it is difficult to characterize the posterior distribution in equation (20), we follow Schorfheide (2005) to factorize the joint posterior as

\[
p(\theta, \phi, S^T|Y^T) = p(\theta, \phi|Y^T)p(S^T|\theta, \phi, Y^T).
\]

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. Sims (2002) optimization routine CSMINWEL is used to find the posterior modes of \(\theta\) and \(\phi\). The inverse Hessian is then calculated at these posterior modes and is used as the covariance matrix of the proposal distribution. It is scaled to yield a target acceptance rate of 25%-40%. We adopt Schorfheide (2005)’s strategy that employs a random walk Metropolis-Hastings algorithm to generate 500,000 draws from \(p(\theta, \phi|Y^T)\), with the first 200,000 draws being discarded and save every 20th draw from the remaining draws.\(^9\) Conditional on the saved draws of parameter vectors, \(\theta\) and \(\phi\), we then utilized Kim (1994)’s smoothing algorithm to generate draws from the history of unobserved states, \(S^T\). Posterior means are obtained by Monte-Carlo averaging.

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

\(^9\)Geweke (1992) convergence diagnostics indicate that convergence is achieved. These are available upon request.
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.

5 Data and Model Priors

5.1 Data

Our empirical analysis uses the aggregate euro area data on output growth, inflation, nominal
interest rates from 1971Q1 up to 2008Q3. 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). The data used in the estimation are plotted in
Figure 2, alongside various counterfactual simulation results which will be discussed below.

5.2 Priors

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, \( \alpha \),
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, \( \varphi \),
and the inverse of the intertemporal elasticity of substitution, \( \sigma \), 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 distribu-
tions to generate realistic volatilities for the endogenous variables. In models that allow for
Markov-switching shock processes, the priors for shock variances are set to be symmetric across
regimes.

Furthermore, for models featuring a simple rule, we use comparatively loose priors for the
policy rule parameters that are consistent with An and Schorfheide (2007) in the case of time-
invariant simple rule. As for Markov-switching rule parameters, in line with Bianchi (2012), the
priors for the response to output growth and the smoothing term are set to be symmetric across

\[\text{The specific data series used are the short-term interest rate - STN, Real Gross Domestic Product-YER and GDP Deflator - YED.}\]
regimes, while asymmetric priors are chosen for the response to inflation.\footnote{This way of setting priors for the switching parameters is also discussed by Davig and Doh (2009), to introduce a natural ordering of regime-dependent parameters and to avoid the potential risk of ‘label switching’ as noted in Hamilton, Waggoner, and Zha (2007).} 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 $\omega_3$ is normalized to 1 in a time-invariant objective function. In the case where $\omega_3$ 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.

The prior for the probability of reneging on past promises under quasi-commitment policy, $\nu$, follows a beta distribution with a mean of 0.3 and standard deviation of 0.02, implying a prior belief that the frequency of policy re-optimizations lies between 8 months and one year. Loosening this prior tends to push the estimated parameter closer to one, such that the quasi-commitment policy reduces to that of discretion. Maintaining a tight prior enables us to explore the implications of describing policy as being a form of quasi-commitment and facilitates a comparison of episodes of re-optimization with other policy switches.

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, $\beta$, such that $\beta = (1 + r^A/400)^{-1}$.

\section{Results}

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, namely discretion, commitment or quasi-commitment. The posterior means and the 90\% confidence intervals obtained from estimating time-invariant models are presented in Table 2 where each column corresponds to an alternative policy description, and these columns are ordered according to log marginal likelihood values calculated using Geweke (1999) and Sims et al. (2008), respectively.\footnote{It is important to note that across all estimations the posterior distributions differ from the prior. The possible exception to this is the estimate of the persistence of the cost-push shock, when policy is described by one of the variants of the simple rule. Nevertheless, the application of the Iskrev (2010) local identification test to the model based on simple rules (and optimal policy under discretion and commitment), is supportive of identification at the central parameter estimates also in this case. In applying the Iskrev (2010) test we examine the rank of the Jacobian of a vector of model parameters across 10,000 draws from the prior distribution, as well as at the prior and posterior means. Plots contrasting prior and posterior distributions are available upon request (and are contained in Figure 1 for our data-preferred estimates based on discretionary policy with Markov switching in conservatism and shock variances).} The first column of results in Table 2 is for the best-fit model, which is time-consistent discretionay policy, followed by a simple rule with shifts in rule parameters,
a similar rule, but with shifts in the inflation target, commitment and the least preferred specification of policy, quasi-commitment. 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) adaption 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”. The probability of reneging on policy promises under the quasi-commitment policy is identified, as its posterior mean, $\nu = 0.293$. Given a quarterly data period, this estimate implies that the quasi-commitment plan is expected to be implemented for about one year. Therefore, these results do not suggest that there is a significant degree of commitment within Euro-area monetary policy.

This then begs the question why are the data apparently inconsistent with policy under commitment, when the rhetoric of central banks would suggest that making credible promises is their raison d’être? We can provide an explanation by exploring the differences in estimates of both the structural model parameters and the shock process hitting our estimated economies as we vary the description of policy. If we consider estimates obtained under the conventional inertial interest rate rule, then our results are broadly in line with other studies: an intertemporal elasticity of substitution, $\sigma$, of 2.76; a measure of price stickiness, $\alpha = 0.745$, implying that price contracts typically last for one year; a relatively modest degree of price indexation, $\zeta = 0.067$, a sizeable estimate of the degree of habits, $\theta = 0.752$ and an inverse Frisch labor supply elasticity of $\varphi = 2.458$. Moving from these estimates obtained under a conventional interest rate rule to the case of optimal policy under discretion, these deep parameter estimates remain largely the same, except that there is a sizeable decline in the degree of habits in the model, which falls to $\theta = 0.50$, and a modest increase in the degree of indexation in price setting to $\zeta = 0.186$. 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 policy under discretion significantly raises the estimated persistence of cost-push shocks in order to fit the data. These differences in estimates across models where policy is described by optimal (but time-consistent) policy rather than an ad hoc rule, reflects the nature of the optimal policy problem. In the absence of inflation inertia and habits, the model would reduce to the benchmark New Keynesian model considered by Woodford (2003) where only cost-push shocks generate a meaningful trade-off for the monetary policy maker, as monetary policy can optimally respond to technology and taste shocks without generating any inflation. Adding inflation indexation to pricing contracts creates further policy trade-offs (see

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13 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.
Steinsson, 2003), as does the externality associated with habits formation (see Leith et al., 2012), both of which would imply that the inflation consequences of taste and technology shocks are no-longer perfectly offset by monetary policy. Accordingly, in order to replicate the observed fluctuations in inflation, optimal policy must be faced with meaningful trade-offs which prevent it from perfectly stabilizing inflation, and the estimated degree of habits, price indexation and cost-push shocks provide the most data coherent means of doing so.

As we increase the level of commitment the policy maker can achieve this alters the trade-offs facing the policy maker further. Although we have constructed an economy that doesn’t experience any inflationary bias problem, any inability to fully commit implies a stabilization bias (Svensson, 1997). This additional bias arises as the policy maker acting without commitment cannot make credible promises as to how she will behave in the future which improves the policy trade-offs she faces today. When the policy maker can commit, she will make promises which enable her to stabilize inflation at a lower cost in terms of fluctuations in real variables. Therefore, in order for commitment policy to be consistent with the observed fluctuations in inflation, the parameter estimates significantly raise the extent of habits, $\theta = 0.664$ as well as the variance $(\sigma_{\mu(s=1)}^2 = 1.633, \sigma_{\mu(s=2)}^2 = 5.676)$ and persistence $(\rho^\mu = 0.961)$ of cost-push shocks.\(^\text{14}\) Therefore, although commitment introduces an inertia to policy which may have been thought useful in explaining the data, it is, in fact, simply too effective in stabilizing inflation to be the data-preferred description of policy.\(^\text{15}\)

6.1 The Great Moderation in Europe

In estimating the various models allowing for policy switches and shock volatility switches we can see that there is evidence of both across all model variants. Under all estimates there are sizeable shifts in the volatility of all shocks between the two volatility regimes. Similarly, the various descriptions of policy also suggest shifts in the conduct of that policy. For example, under discretion and commitment, the weight on inflation in the policy maker’s objective function falls from 1 to 0.477 and 0.625, respectively. While the policy rule with shifts in parameters moves from an active policy,

$$R_t = 0.820R_{t-1} + (1 - 0.820)[2.362\tilde{\pi}_{t-1} + 0.478(\Delta\hat{y}_t + \hat{z}_t)]$$

\(^\text{14}\)It should be noted that the cost-push shock enters the Phillips curve with the reduced form coefficient $\kappa_c$, which lies in the range 0.1-0.3 across our estimates.

\(^\text{15}\)We shall turn to evaluate the gains to both optimal policy in general, and commitment in particular in Section 7.
to a mildly passive and less inertial rule,

\[
R_t = 0.769 R_{t-1} + (1 - 0.769)[0.933\tilde{\sigma}_t + 0.292(\Delta\tilde{g}_t + \tilde{z}_t)]
\]  

Similarly, for the rule with a shift in the inflation target, that target rises from 3.2% to 4% during periods of less conservative policy. While in the case of quasi-commitment we do not allow for shifts in policy maker preferences, but instead identify periods in which the likelihood of reneging on past policy promises are high. The timing and probability of these policy switches and shock volatility switches are given in Figure 2.

These show broadly similar patterns of shock volatility with high volatility in the early sample period, lasting until the early 1980s. 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 the rule-based estimates the first additional burst of volatility appears to be associated with the stock market crash of 1987 (a similar episode can be identified in the data for the US, see Chen et al., 2013) with a second occurring around 1992 as tensions in the ERM led to the UK and Italy exiting the ERM This tension is usually attributed to the unsuitability of a monetary policy designed for German domestic conditions following reunification, for other ERM economies (see, Buiter et al., 2008). Interestingly, the data-preferred model (featuring a discretionary description of Euro-area monetary policy) suggests that there was really only a brief fall in shock volatilities in the early 1980s before they re-emerged well before the stock market crash of 1987. 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. Finally, the burst of volatility associated with the dot-com crash of 2000 in the US (Chen et al., 2013) does not appear to be a significant feature of estimations for the Euro-area, except for the mildest of blips in the discretion-based estimates, where this may also reflect the creation of the Euro.

In terms of shifts in policy, all the estimates point to a less aggressive anti-inflation stance in the 1970s. The adoption of the ERM in 1979 does not appear to have immediately resulted in switch in the conservatism of policy, although 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 standard approach of allowing for switches in policy rule parameters, such that policy moves from a passive to active rule, the conservatism would be seen to emerge around the time of the hardening of the ERM in 1987. Allowing for switches in the inflation target embodied in the rule would imply a more gradual attainment of conservatism, beginning in the early 1980s, but not being completed until
the 1990s. While our data-preferred description of policy as being that of discretion suggests that the initial move towards a more conservative policy stance took place a couple of years after the launch of the ERM.\textsuperscript{16}

As in rule-based estimates for the US, the estimation based on simple policy rules offers little more information than this well-known shift in policy. In contrast, the 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 was harming their economies.\textsuperscript{17} Similarly, in the run-up to the creation of the Euro, the estimates suggest that policy gradually lost conservatism. To the extent that the Euro-area wide data are capturing German monetary leadership in this period, it suggests that perhaps the Bundesbank was not so insensitive to the needs of their ERM/Euro-area partners as is often suggested. 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 (less data-coherent) descriptions of policy.

\section{Counterfactuals}

Our best-fit 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, exploring what the outcomes would have been if shock volatilities had not declined in the 1980s, or what would have happened had policy makers in the Euro-area adopted a tougher anti-inflation stance in the 1970s. Moreover, we can explore how much further welfare would have improved had the policy maker not only adopted tougher anti-inflation policies in the 1980s, but also been able to act under commitment.\textsuperscript{18}

\textsuperscript{16}Our estimates for the US under discretionary policy (see Chen et al., 2013) reveal that the timing of the Volcker disinflation occurs in early 1982 rather than break in estimated policy rules which occurs in 1979. Therefore, the data-preferred model for the US also offers a different dating of a key policy shift relative to conventional rule-based estimates, but delaying it rather than bringing it forward in time.

\textsuperscript{17}Buiter et al. (1998), 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.

\textsuperscript{18}In the following section we consider alternative delegation schemes as a means of capturing some of the gains to commitment.
We begin our counterfactuals by analyzing the role of ‘good luck’ in stabilizing Euro-area output and inflation. To do so we fixed the pattern of switches in policy regimes to those estimated from the data, but consider the counterfactual where the volatility of shocks is either at its high or low value. We take the estimated shocks and re-scale them by the relative standard deviations from the high and low volatility regimes, so that similar kinds of shock are imposed, but they are scaled to mimic the standard deviations observed under the two volatility regimes. Figure 3 plots the actual and counterfactual series for inflation, interest rates and output growth. We can see that the high volatility of shocks plays a significant role in raising inflation during the 1970s. In the absence of these high volatility shocks, inflation would have been significantly lower in the 1970s. In addition, it is apparent that output growth fluctuations could have been dampened if policy makers had had the ‘good luck’ of the low shock volatility regime during the 1970s and early 1980s.

Moreover, we should also note that under the conservative policy regime, inflation and output fluctuations would not have changed too dramatically regardless of the magnitude of shocks. This may be an indication that tougher anti-inflation policies in the 1980s helped in stabilizing the Euro-area economy.

Therefore, in the second set of counterfactual analysis, we assess the impact that increased conservatism would have had on Euro-area inflation and output, especially during the 1970s. To do so, we reinsert the estimated shock processes back in the model and fix the weight on inflation in the objective function, $\omega_\pi$, to either their high or low conservatism values of 1 or 0.477, respectively, throughout the sample period. Figure 4 plots the actual and counterfactual series for inflation and interest rates, as well as output losses with $\omega_\pi = 1$ for the entire sample period. Output losses are the difference between model implied output with estimated objective function weights and the counterfactual output when policy maker is more conservative, $\omega_\pi = 1$. The first panel of Figure 4 shows that even if Euro-area policy makers had adopted a tougher anti-inflation stance in the 1970s, they would not have been able to completely avoid higher inflation, but observed inflation would have been significantly lowered at a cost of the output losses as shown in Panel 3 of Figure 4.

Finally, in Figure 5 we keep the shock volatility and policy switches fixed at their estimated values, and vary whether or not the policy-maker has access to a commitment technology. That is, we assess the implications of moving from discretion to commitment, \textit{cet. par.} The results are striking. If Euro-area policy makers had been able to make credible policy commitments in the 1970s, even although the Euro-area economy was subject to high volatility shocks and reduced the
weight attached to inflation stabilization in that period, inflation would have remained below 5\% throughout the sample period. Although it appears that there would have been non-trivial losses in output as a result of the commitment policy. However, our welfare analysis below, suggests that these losses are more than compensated for by the reduction in inflation volatility. Finally Figure 5 also contains a series labelled “optimal” discretion. This series is the outcomes under discretion where we re-optimize the weight the policy maker attaches to inflation assuming that she was appointed by a society which had preferences identical to those we estimate. In this application of Rogoff’s conservative central banker device, the optimal weight on inflation rises from 1 to 6.99, and we see a substantial reduction in inflation, particularly in the 1970s, although there is a cost in terms of lost output in appointing such a conservative central banker. This highlights the potential importance of designing appropriate monetary policy delegation schemes and we explore this issue further in the next section.

In addition to providing counterfactual figures, we also compute the unconditional variances of key variables, as well as the value of unconditional welfare (both using the policy maker’s estimated weights and the measure of utility that would be consistent with the estimated structural parameters) 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 adopts the high shock volatility regime in conjunction with discretionary policy with the lower level of estimated conservatism, $\omega_\pi = 0.477$. 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 either an increase in central bank conservatism or reduction in shock volatility alone would reduce more than half of the volatility in inflation and interest rates implied by the worst case scenario. However, it is the ‘good luck’ that could also lead to significant output stabilization and therefore achieve bigger gains in 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. At first sight 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. However, 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. Finally, under commitment we again see large decreases in output volatility when there is ‘good luck’ reducing shock volatilities.

8 Alternative Delegation Schemes

The counterfactual analysis suggests that 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 an typically replace the inflation target with an alternative target which introduces some of the inertia 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 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. 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 inflation purely backward looking will negate any of the expectation advantages offered by any of these schemes.

\[ ^{19}\text{In fact, with iid shocks, price level targeting can be shown to be isomorphic to the full commitment solution when the New Keynesian Phillips curve is purely forward looking.} \]
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 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,

$$L = -\frac{1}{2}N^{1+\varphi}E_0 \sum_{t=0}^{\infty} \beta^t \left\{ \frac{\sigma(1-\theta)}{1-\theta \beta} \left( \hat{X}_t + \hat{\xi}_t \right)^2 + \varphi \left( \hat{y}_t - \frac{\sigma}{\varphi} \hat{\xi}_t \right)^2 \right\} + tip + O[2]$$  (23)

Secondly, we can consider the same form of objective function, but use the estimated weights,

$$\Gamma = -N^{1+\varphi} \frac{1}{2} E_0 \sum_{t=0}^{\infty} \beta^t \left\{ \omega_1 \left( \hat{X}_t + \hat{\xi}_t \right)^2 + \omega_2 \left( \hat{y}_t - \frac{\sigma}{\varphi} \hat{\xi}_t \right)^2 + \left( \hat{\pi}_t + \frac{\xi \alpha^{-1}}{1-\xi} \left[ \hat{\pi}_t - \hat{\pi}_{t-1} \right]^2 \right) \right\},$$  (24)

Thirdly, we can backward engineer the measure of social welfare that would have made delegation of policy to a ‘conservative’ central banker, whose preferences mirror those that were estimated, optimal. This last case is essentially assumes that society employed the conservative central banker device of Rogooff (1985) to improve the outcomes under discretion, so that the observed
policy can be used to reveal society’s preferences. Therefore, society’s preferences are given by,

$$
\Gamma = -N^{1+\varphi} \frac{1}{2} E_0 \sum_{t=0}^{\infty} \beta^t \left\{ \omega_1 \left( \hat{X}_t + \hat{\xi}_t \right)^2 + \omega_2 \left( \hat{y}_t - \frac{\sigma}{\varphi} \hat{\xi}_t \right)^2 + \omega_\pi \left( \hat{\pi}_t + \frac{\varsigma \alpha^{-1}}{1-\varsigma} \left[ \hat{\pi}_t - \hat{\pi}_{t-1} \right] \right) \right\},
$$

(25)

where \( \omega_1 \) and \( \omega_2 \) are the estimated weights, and \( \omega_\pi \) is the weight society attaches to inflation stabilization such that it is optimal to appoint a conservative central banker with the estimated preference function, (24). We describe this implied weight on inflation stabilization in society’s welfare function as being the ‘revealed preference’ weight. Using our median parameter estimates the ‘revealed preference’ inflation weight is \( \omega_\pi = 0.1229 \), roughly one eighth of the inflation weight implied by the estimated objective function.

Moving through the three options effectively reduces the weight we would assume society attaches to inflation stabilization, relative to the real elements in the objective function. We have explored all three approaches. The first approach (using micro-founded weights and estimated parameters) attaches such a large weight to inflation that all optimized delegation schemes are negligibly different from a policy of strict inflation targeting. The second approach treats the estimated objective function as being synonymous with social welfare. The final approach, uses the observed policy to infer that society’s objective function must have attached a weight to inflation of 0.1229 rather than the observed weight of 1, cet. par.

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

$$
\Gamma_p = -N^{1+\varphi} \frac{1}{2} E_0 \sum_{t=0}^{\infty} \beta^t \left\{ \omega_1 \left( \hat{X}_t + \hat{\xi}_t \right)^2 + \omega_2 \left( \hat{y}_t - \frac{\sigma}{\varphi} \hat{\xi}_t \right)^2 + \omega_p \left( \hat{p}_t \right) \right\},
$$

(26)

where \( \hat{p}_t = \hat{p}_{t-1} + \hat{\pi}_t \). Using either the ‘revealed’, estimated or micro-founded values of \( \omega_1 \) and \( \omega_2 \), we shall then select the values of \( \omega_p \) which maximize estimated and micro-founded utility, respectively. Similarly for nominal income growth targeting, our objective function is given by,

$$
\Gamma_{NI} = -N^{1+\varphi} \frac{1}{2} E_0 \sum_{t=0}^{\infty} \beta^t \left\{ \omega_1 \left( \hat{X}_t + \hat{\xi}_t \right)^2 + \omega_2 \left( \hat{y}_t - \frac{\sigma}{\varphi} \hat{\xi}_t \right)^2 + \omega_{NI} \left( \hat{y}_t - \hat{y}_{t-1} + z_t + \hat{\pi}_t \right)^2 \right\},
$$

(27)

where \( \hat{y}_t - \hat{y}_{t-1} + z_t + \hat{\pi}_t \) captures the growth in nominal GDP relative to its trend. Again, \( \omega_{NI} \) shall be chosen to maximize social welfare, where that is either defined by equation (18) using revealed, estimated or micro-founded weights.
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,

$$\Gamma_{SL} = -\sum_{t=0}^{\infty} \beta^t \left\{ \left( \pi_t^2 + \frac{\zeta \alpha^{-1}}{1 - \zeta} \left( \hat{\eta}_t - \hat{\eta}_{t-1} \right)^2 \right) + \omega_{SL}(\hat{y}_t - \hat{y}_{t-1})^2 \right\},$$  \hspace{1cm} (28)

Using the various social welfare metrics described above we obtain the optimal weights within each of our four delegation schemes: inflation targeting, nominal income growth targeting, speed limit policies and price level targeting. To do so we make 200 draws from our posterior distribution of parameters and obtain the optimized weight for each delegation scheme for each draw. The median of these optimized weights shall then be the chosen weight for that delegation scheme in the subsequent counterfactual analysis. These are reported in Table 3.

The optimization of the weights within the various delegation schemes reveals several features of optimal policy. Firstly, micro-founded losses imply a very aggressive response to inflation under all delegation schemes other than nominal income growth targets with inflation and price level targets effectively resulting in strict inflation targeting, while speed limit policies are almost as aggressive. Nominal income growth target cannot mimic strict inflation targeting, which implies it does not do as well in terms of minimizing welfare losses. As the optimal delegation schemes under micro-founded weights imply a policy of strict inflation targeting which is clearly unrealistic we do not pursue this description of policy further, although we do compute the micro-founded assessment of losses under the alternative parameterization of the various delegation schemes. The second column suggests that if social welfare was given by our estimated loss function, society would have maximized its welfare by appointing a conservative central banker with a 7-fold increase in inflation aversion relative to that of society. Similarly, using ‘revealed preferences’ as our guide to the design of delegation schemes would imply a significantly less aggressive response to inflation volatility.\footnote{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 often restrict the coefficient on excess inflation to avoid optimized values rising to implausibly high levels (see, for example, Schmitt-Grohe and Uribe, 2007).}

We next consider the macroeconomic outcomes under each of these delegation schemes optimally designed using our estimated objective function - see Table 3. Before turning to consider the policies that would emerge under remits designed to maximize our ‘revealed preference’ measure of social welfare. Having shown in Figure 5 that appointing a conservative central banker
would have substantially reduced inflation in the 1970s, and raised welfare despite the output losses this would have implied, we now turn to consider the merits of the various delegation schemes outlined above. Figure 6 shows that, treating social welfare as being synonymous with our estimated objective function, all the suggested delegation schemes would have substantially reduced inflation in the 1970s and 1980s. 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 4 which plots welfare measures and output, inflation and interest rate variances under our high and low volatility regimes. Here nominal income growth targets are clearly the least successful policy in terms of output and 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.

Figure 7 performs the same exercise, but using the ‘revealed preference’ measure of social welfare. In this case the relative ranking of delegation schemes is the same as before, although now the schemes are unable to bring inflation consistently below 5% in the 1970s. Here we can see the nominal income growth target, while successfully reducing inflation pays a very high price in terms of lost output, which is why it performs so poorly in welfare terms. Essentially the technology shocks, particularly in the 1970s result in an inappropriate policy response under nominal income growth targets. While price level targeting and speed limit policies both successfully reduce inflation in the 1970s (and reduce its volatility thereafter) the output losses under speed limit policies substantially reduce their efficacy. In short, our estimated model suggests that price level targets very flexibly applied (the weight on the price level target is small) bring the outcomes closes to those under commitment.

Finally, Figure 8 contrasts the outcomes under our observed policy (discretion) assuming that the central banker has been chosen by society to be optimally conservative, with the outcomes that would be achieved has society been able to appoint someone who accurately reflected their preferences and was able to make credible policy commitments. Here we see that the gains to commitment remain high, even if we assume that the policy under discretion is as good as it can possibly be in that the policy maker’s preferences have been chosen optimally. 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.

These results are confirmed in Tables 4 and 5, respectively. Regardless of the volatility regime and whether social welfare is measured by our estimated or ‘revealed preference’ weights, flexible price level targeting emerges as the optimal delegation scheme. This implies that such delegation
schemes are not just appropriate for good times, but would have yielded substantial benefits under the high volatility regime of the 1970s too.

9 The ZLB

[This section is incomplete]

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. In this section we derive the policy problem facing the policy maker who recognizes the ZLB constraint. We then assess the extent to which the alternative delegation schemes we considered above mitigate against such a constraint given that the policy maker has been found not make credible commitments within our sample period.

The objective function for our policy maker is given by,

$$\Gamma = -N^{1+\varphi} \frac{1}{2} \beta^t \sum_{t=0}^{\infty} \beta^t \left\{ \omega_1 \left( \hat{X}_t + \hat{\xi}_t \right)^2 + \omega_2 \left( \hat{y}_t - \frac{\sigma}{\varphi} \hat{\xi}_t \right)^2 + \left( \alpha^t_1 + \frac{\zeta \alpha^{-1}}{1 - \zeta} \left[ \hat{\pi}_t - \hat{\pi}_{t-1} \right]^2 \right) \right\}, \quad (29)$$

with constraints implied by the definition of habits,

$$\hat{X}_t = (1 - \theta)^{-1}(\hat{c}_t - \theta \hat{c}_{t-1}) \text{ Habits-Adjusted Consumption} \quad (30)$$

$$\hat{X}_t = \mathbb{E}_t \hat{X}_{t+1} - \frac{1}{\sigma} \left( \hat{R}_t - \mathbb{E}_t \hat{\pi}_{t+1} - \mathbb{E}_t \hat{\pi}_{t+1} \right) - \hat{\xi}_t + \mathbb{E}_t \hat{\xi}_{t+1} \text{ Euler Equation} \quad (31)$$

$$\hat{\pi}_t = \chi_f \beta \mathbb{E}_t \hat{\pi}_{t+1} + \chi_b \hat{\pi}_{t-1} + \kappa_c (\sigma \hat{X}_t + \varphi \hat{c}_t + \hat{\mu}_t), \text{ Hybrid NKPC} \quad (32)$$

as well as the evolution of the three exogenous shock processes,

$$\hat{z}_t = \rho^* \hat{z}_{t-1} + \varepsilon_{z,t} \text{ Technology Shock} \quad (33)$$

$$\hat{\mu}_t = \rho^\mu \hat{\mu}_{t-1} + \varepsilon_{\mu,t} \text{ Cost-Push Shock} \quad (34)$$

$$\hat{\xi}_t = \rho^\xi \hat{\xi}_{t-1} + \varepsilon_{\xi,t} \text{ Preference Shock} \quad (35)$$

Within the constraints there are three endogenous expectations terms, which can be re-written in terms of the following state-dependent auxiliary functions,

$$\mathbb{E}_t \hat{\pi}_{t+1} = \mathbb{E}_t N(\hat{c}_t, \hat{\pi}_t, ...)$$

32
Therefore we can write the Lagrangian for the policy problem facing the policy maker acting under discretion as,

\[ L_t = \frac{1}{2} \left( \omega_1 \left( \hat{X}_t + \hat{\xi}_t \right)^2 + \omega_2 \left( \hat{\xi}_t - \frac{\sigma}{\varphi} \hat{\zeta}_t \right)^2 + \left( \hat{\pi}_t - \frac{\zeta \alpha^{-1}}{1 - \zeta} \left[ \hat{\pi}_t - \hat{\pi}_{t-1} \right]^2 \right) \right) \\
+ \lambda_t^1 \left( \hat{X}_t - (1 - \theta)^{-1} (\hat{c}_t - \theta \hat{c}_{t-1}) \right) \\
+ \lambda_t^2 \left( \hat{X}_t - \mathbf{E}_t M(.) \right) + \frac{1}{\sigma} \left( \hat{R}_t - \mathbf{E}_t N(.) - \rho \hat{\zeta}_t \right) + (1 - \rho^2) \hat{\xi}_t \\
+ \lambda_t^3 \left( \hat{\pi}_t - \chi_f \beta \mathbf{E}_t N(.) - \chi_b \hat{\pi}_{t-1} - \kappa_c (\sigma \hat{X}_t + \varphi \hat{\xi}_t + \hat{\mu}_t) \right) \\
+ \lambda_t^4 \left( \hat{R}_t \geq R^* \right) \\
+ \beta \mathbf{E}_t V(\hat{c}_t, \hat{\pi}_t, ...) \]

where we have imposed the constraint that interest rate cannot fall below the level \( R^* \), and have defined the value of future payoffs given the values of inherited state variables as, \( V(\hat{c}_t, \hat{\pi}_t, ...) \).

The resultant first order conditions are as follows:

\( \hat{X}_t : \)

\[ \omega_1 \left( \hat{X}_t + \hat{\xi}_t \right) + \lambda_t^1 + \lambda_t^2 - \kappa_c \sigma \lambda_t^3 = 0 \]

\( \hat{R}_t : \)

\[ \frac{1}{\sigma} \lambda_t^2 + \lambda_t^4 = 0 \]

where the complementary slackness condition implies, \( \lambda_t^4 (\hat{R}_t - R^*) = 0 \).

\( \hat{\pi}_t : \)

\[ 0 = \hat{\pi}_t + \frac{\zeta \alpha^{-1}}{1 - \zeta} \left[ \hat{\pi}_t - \hat{\pi}_{t-1} \right] - \lambda_t^2 \left( \frac{\partial \mathbf{E}_t M(.)}{\partial \hat{\pi}_t} \right) + \frac{1}{\sigma} \frac{\partial \mathbf{E}_t N(.)}{\partial \hat{\pi}_t} \\
+ \lambda_t^3 \left( 1 - \chi_f \beta \mathbf{E}_t \frac{\partial N(.)}{\partial \hat{\pi}_t} \right) + \beta \mathbf{E}_t \frac{\partial V(.)}{\partial \hat{\pi}_t} \]

\( \hat{c}_t : \)

\[ 0 = \omega_2 \left( \hat{c}_t - \frac{\sigma}{\varphi} \hat{\xi}_t \right) - \lambda_t^1 (1 - \theta)^{-1} - \lambda_t^2 \left( \mathbf{E}_t \frac{\partial M(.)}{\partial \hat{c}_t} \right) + \frac{1}{\sigma} \frac{\partial \mathbf{E}_t N(.)}{\partial \hat{c}_t} \\
- \lambda_t^3 \left( \chi_f \beta \mathbf{E}_t \frac{\partial N(.)}{\partial \hat{c}_t} + \kappa_c \varphi \right) + \beta \mathbf{E}_t \frac{\partial V(.)}{\partial \hat{c}_t} \]

While the partials with respect to the states, \( \hat{c}_{t-1} \), and \( \hat{\pi}_{t-1} \) are given by:

\( \hat{c}_{t-1} : \)

\[ \lambda_t^1 \theta (1 - \theta)^{-1} - \frac{\partial V(.)}{\partial \hat{c}_{t-1}} = 0 \]

33
\hat{c}_{t-1}:
\[-\frac{\zeta \alpha^{-1}}{1 - \zeta} [\hat{\pi}_t - \hat{\pi}_{t-1}] - \chi_b \lambda_t^3 - \frac{\partial V(\cdot)}{\partial \hat{\pi}_{t-1}} = 0\]

Leading and taking expectations implies,
\[\beta E_t \frac{\partial V(\cdot)}{\partial c_t} = \beta \theta (1 - \theta)^{-1} E_t \lambda_{t+1}^1\]

and,
\[\beta E_t \frac{\partial V(\cdot)}{\partial \hat{\pi}_t} = -\frac{\zeta \alpha^{-1}}{1 - \zeta} [E_t \hat{\pi}_{t+1} - \hat{\pi}_t] - \chi_b E_t \lambda_{t+1}^3\]

9.1 Setting up in a way suitable for coding:

We allow for four policy functions for \(\hat{c}_t, \hat{\pi}_t, \lambda_t^1\) and \(\lambda_t^3\).

Given these functions, we can immediately define the level of habits adjusted consumption,
\[\hat{X}_t = (1 - \theta)^{-1} (\hat{c}_t - \theta \hat{c}_{t-1})\]

and use the consumption Euler equation to check if the ZLB bites. This occurs when,
\[-\sigma(\hat{X}_t - E_t M(\cdot)) + \frac{1}{\sigma} (-E_t N(\cdot) - \rho^2 \hat{z}_t) + (1 - \rho^2) \hat{\pi}_t) < R^*\]

In this case \(\hat{R}_t = R^*\) and
\[\lambda_t^2 = -\omega_1 \left( \hat{X}_t + \hat{\xi}_t \right) - \lambda_t^1 + \kappa_c \sigma \lambda_t^3\]

and
\[\lambda_t^4 = -\frac{1}{\sigma} \lambda_t^2\]

and the four functions which are used to update the policy functions are (i) the foc for inflation,
\[0 = \hat{\pi}_t + \frac{\zeta \alpha^{-1}}{1 - \zeta} [\hat{\pi}_t - \hat{\pi}_{t-1}] - \lambda_t^2 (E_t \frac{\partial M(\cdot)}{\partial \hat{\pi}_t}) + \frac{1}{\sigma} E_t \frac{\partial N(\cdot)}{\partial \hat{\pi}_t} + \lambda_t^3 (1 - \chi_f \beta E_t \frac{\partial N(\cdot)}{\partial \hat{\pi}_t}) - \frac{\zeta \alpha^{-1}}{1 - \zeta} [E_t \hat{\pi}_{t+1} - \hat{\pi}_t] - \chi_b E_t \lambda_{t+1}^3\]

(ii) the foc for consumption,
\[0 = \omega_2 \left( \hat{c}_t - \frac{\sigma}{\phi} \hat{\xi}_t \right) - \lambda_t^1 (1 - \theta)^{-1} - \lambda_t^3 (E_t \frac{\partial M(\cdot)}{\partial c_t}) + \frac{1}{\sigma} E_t \frac{\partial N(\cdot)}{\partial c_t} - \lambda_t^3 (\chi_f \beta E_t \frac{\partial N(\cdot)}{\partial c_t} + \kappa_c \phi) + \beta \theta (1 - \theta)^{-1} E_t \lambda_{t+1}^3\]

34
(iii) the consumption Euler equation,

$$\tilde{X}_t - \mathbb{E}_t M(\cdot) + \frac{1}{\sigma} \left( \hat{R}_t - N(\cdot) - \rho^2 \hat{z}_t \right) + (1 - \rho^2) \hat{\xi}_t = 0$$

and (iv) the New Keynesian Phillips curve,

$$\hat{\pi}_t - \chi E_t \mathbb{E}_t N(\cdot) - \chi_b \hat{\pi}_{t-1} - \kappa_c (\sigma \hat{X}_t + \varphi \hat{\pi}_t + \hat{\mu}_t) = 0$$

While if

$$-\sigma (\tilde{X}_t - M(\cdot) + \frac{1}{\sigma} (-\mathbb{E}_t N(\cdot) - \rho^2 \hat{z}_t) + (1 - \rho^2) \hat{\xi}_t) \geq R^*$$

the ZLB doesn’t bite, \( \lambda^4_t = \lambda^3_t = 0 \) and \( \hat{R}_t = -\sigma (\tilde{X}_t - M(\cdot) + \frac{1}{\sigma} (-N(\cdot) - \rho^2 \hat{z}_t) + (1 - \rho^2) \hat{\xi}_t) \). In this case the four functions being used to update the policy functions are the same except that the consumption Euler equation is replaced with the foc for \( X \),

$$\omega_1 \left( \tilde{X}_t + \tilde{\xi}_t \right) + \lambda^1_t + \lambda^2_t - \kappa_c \sigma \lambda^3_t = 0$$

Without the ZLB constraint the existing solution can be used to set up the policy functions. We shall have solutions for \( \hat{X}_t, \hat{\pi}_t \) and \( \hat{\xi}_t \) as a function of states from the LQ solution. Similarly the partials wrt to the state variables will match with the LQ solution to the policy problem without the ZLB to obtain the policy functions for the two Lagrange multipliers,

$$\lambda^1_t = \theta^{-1} (1 - \theta) \frac{\partial V(\cdot)}{\partial \xi_{t-1}}$$

$$\lambda^3_t = - (\chi_b)^{-1} \left[ \frac{\zeta}{1 - \zeta} \left[ \hat{\pi}_t - \hat{\pi}_{t-1} \right] + \chi_b \lambda^3_t + \frac{\partial V(\cdot)}{\partial \hat{\pi}_{t-1}} \right]$$

10 Conclusions

In this paper we explored the implications of describing policy using various notions of optimal policy, namely discretion, commitment and quasi-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 around 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 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’ (a reduction in shock volatilities) and ‘good policy’ (an increase in monetary policy conservatism) 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 1970s.

Given the potential gains to improving the credibility of policy making, we conclude by considering to what extent alternative delegations schemes - price level targets, inflation targets, speed limit policies and nominal GDP 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 welfare function and the measure of social welfare that would be consistent with society choosing to appoint a central banker with the preferences we estimate, 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, so that it would also have been optimal to adopt such a central bank remit in the 1970s as well as in less volatile periods.

In ongoing work we intend to assess the importance of the ZLB constraint across our delegation schemes and the ability of alternative forms of forward guidance to mitigate the costs of this constraint.
References


A The Complete Model

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

\[
N_t = W_t A_t (1 - \tau_t) \equiv w_t (1 - \tau_t) \tag{36}
\]

\[
\left( \frac{X_t}{A_t} \right)^{-\sigma} \xi_t^{-\sigma} = \beta \mathbb{E}_t \left[ \left( \frac{X_{t+1}}{A_{t+1}} \right)^{-\sigma} \frac{A_t}{A_{t+1}} \xi_{t+1}^{-\sigma} R_{t+1} \right] \tag{37}
\]

\[
N_t = Y_t \int_0^1 \left( \frac{P_t(i)}{P_t} \right)^{-\eta} di \tag{38}
\]

\[
X_t = C_t - \theta C_{t-1} \tag{39}
\]

\[
Y_t = C_t \tag{40}
\]

\[
\tau_t W_t N_t = -T_t \tag{41}
\]

\[
P_t^f / P_t = \eta \left( \frac{\eta - 1}{\mathbb{E}_t} \right) \sum_{s=0}^{\infty} (\alpha \beta)^s \left( \frac{X_{t+s+1}}{A_{t+s}} \right)^{-\sigma} m_{t+s} \left( \frac{P_{t+s}^{-\sigma}}{P_t} \right)^{\eta-1} \frac{Y_{t+s}}{A_{t+s}} \tag{42}
\]

\[
m_{t} = \frac{W_t}{A_t P_t} \tag{43}
\]

\[
P_t^b = P_{t-1}^{\eta} \tag{44}
\]

\[
\ln P_t = (1 - \zeta) \ln P_t^f + \zeta P_t^b \tag{45}
\]

\[
P_t^{1-\eta} = \alpha (\pi P_{t-1})^{1-\eta} + (1 - \alpha) (P_t^*)^{1-\eta} \tag{46}
\]

\[
\ln A_t = \ln \gamma + \ln A_{t-1} + \ln z_t \tag{47}
\]

\[
\ln z_t = \rho \ln z_{t-1} + \varepsilon_{z,t} \tag{48}
\]

\[
\ln(1 - \tau_t) = \rho^\mu \ln(1 - \tau_{t-1}) + (1 - \rho^\mu) \ln(1 - \tau) - \varepsilon_t^\mu \tag{49}
\]

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:

\[ N^\rho X^\sigma = w(1 - \tau) \]

\[ 1 = \beta R \pi^{-1}/\gamma = \beta r/\gamma \]

\[ y = N = c \]

\[ X = c(1 - \theta) \]

\[ \eta \eta - 1 = \frac{1}{w} \]

This system yields

\[ N^{\sigma + \rho} (1 - \theta)^\sigma = w(1 - \tau). \tag{50} \]

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:

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

\[ s.t. \quad Y_t^* = C_t^* \]

\[ Y_t^* = A_t N_t^* \]

\[ X_t^* = C_t^*/A_t - \theta C_{t-1}^*/A_{t-1} \]

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

\[ \chi(N_t^*)^\rho (X_t^*)^\sigma = (1 - \theta \beta) \mathbb{E}_t \left( \frac{X_{t+1}^* \xi_{t+1}}{X_t^* \xi_t} \right)^{-\sigma}. \]
The steady state equivalent of this expression can be written as

\[ \chi (N^*)^{\gamma+\sigma} (1-\theta)^\sigma = (1-\theta\beta). \]

If we contrast this with the allocation achieved in the steady-state of our decentralized equilibrium (50) we can see that the two will be identical whenever the tax rate is set optimally to be

\[ \tau^* = 1 - \frac{\eta}{\eta-1} (1-\theta\beta). \]

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 over-consuming.

### C Derivation of Objective Function

Individual utility in period \( t \) is

\[ \Gamma_0 = E_0 \sum_{t=0}^{\infty} \beta^t \left( \frac{X_{1-t}^{1-\sigma} \xi_{1-t}^{\sigma-1}}{1-\sigma} - \frac{N_{1-t}^{1+\sigma} \xi_{1-t}^{\sigma-1}}{1+\varphi} \right) \]

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

\[ \Gamma_0 = E_0 \sum_{t=0}^{\infty} \beta^t \left( \frac{1}{1-\theta} \left( c_t + \frac{1}{2} c_t^2 \right) - \frac{1}{2} \sigma \hat{X}_t^2 - \sigma \hat{X}_t \hat{\xi}_t \right) \]

\[ -N_1^{1+\sigma} \left( \hat{N}_t + \frac{1}{2} (1+\varphi) \hat{N}_t^2 - \sigma \hat{N}_t \hat{\xi}_t \right) \] + tip(3).

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 \( \hat{Z}_t = \log(Z_t/Z) \).

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 \( \Delta_t = \int_0^1 \left( \frac{P_i(a)}{T_i} \right)^{-\eta} d_i \). We substitute \( \hat{N}_t \) out and follow Eser et al. (2009) in using

\[ \sum_{t=0}^{\infty} \beta^t \Delta_t = \frac{\alpha}{1-\alpha\beta} \Delta_{-1} + \frac{1}{2} \sum_{t=0}^{\infty} \beta^t \frac{\alpha \eta}{(1-\beta \alpha)(1-\alpha)} \left( \hat{\pi}_t^2 + \frac{\zeta \alpha^{-1}}{(1-\zeta)} [\hat{\pi}_t - \hat{\pi}_{t-1}]^2 \right) \]
to yield
\[
\Gamma_0 = \mathbb{E}_0 \sum_{t=0}^{\infty} \beta_t \left( \bar{X}^{1-\sigma} \left\{ \frac{1-\theta \beta}{1-\theta} \left( \hat{c}_t + \frac{1}{2} \hat{\sigma}^2 \right) - \frac{1}{2} \sigma \hat{X}_t^2 - \sigma \hat{X}_t \hat{\xi}_t \right\} 
- \bar{N}^{1+\varphi} \left( \hat{y}_t + \frac{1}{2} \left( \frac{\alpha \eta}{(1-\beta \alpha)(1-\alpha)} \left( \hat{\pi}_t^2 + \frac{\zeta \alpha^{-1}}{1-\zeta} [\hat{\pi}_t - \hat{\pi}_{t-1}]^2 \right) + \frac{1}{2} (1+\varphi) \hat{y}_t^2 - \sigma \hat{y}_t \hat{\xi}_t \right) \right) + \text{tip}(3). \]

The second order approximation to the national income identity yields
\[
\hat{c}_t + \frac{1}{2} \hat{\sigma}^2 = \hat{y}_t + \frac{1}{2} \hat{y}_t^2 + \text{tip}(3). \]

Finally, we use that in the efficient steady-state \( \bar{X}^{1-\sigma} (1-\theta \beta) = (1-\theta) \bar{N}^{1+\varphi} \) and collect terms to arrive at
\[
\Gamma_0 = -\frac{1}{2} \bar{N}^{1+\varphi} \mathbb{E}_0 \sum_{t=0}^{\infty} \beta_t \left\{ \frac{\sigma (1-\theta)}{1-\theta \beta} \left( \hat{\xi}_t + \hat{c}_t \right)^2 + \varphi \left( \hat{y}_t - \frac{\sigma}{\varphi} \hat{\xi}_t \right)^2 \right. \\
+ \frac{\alpha \eta}{(1-\beta \alpha)(1-\alpha)} \left( \hat{\pi}_t^2 + \frac{\zeta \alpha^{-1}}{1-\zeta} [\hat{\pi}_t - \hat{\pi}_{t-1}]^2 \right) \left. \right\} + \text{tip}(3). \]

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 (18). The welfare costs using micro-founded weights is based on equation (12), 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.
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

Discretion
- less conservative
- high volatility

Commitment
- less conservative
- high volatility
- target

Quasi-Commitment
- reoptimisation
- high volatility

Simple Rule
- passive monetary policy
- high volatility

Simple Rule
- higher inflation target
- high volatility
Figure 3: Counterfactuals under Different Volatility Regimes

Inflation

Output

Interest Rate

data  high volatility regime  low volatility regime
Figure 4: Counterfactuals under Different Levels of Conservatism

Notes: Lower panel plots the difference between output observed given the model account of regime switches and output attained if only the conservatism regime is realized.
Figure 5: Counterfactuals: Commitment versus Discretion

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 $\omega_x = 1$, discretion with $\omega_x = 6.99$ and commit cet. par.
Figure 6: 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.
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 8: 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.
Table 1: Distribution of Priors

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Markov Switching s.d. of shocks

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Markov switching rule parameters

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Weights on Objectives

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Markov switching in Inflation Target

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Transition Probabilities

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Table 2: Estimation Results - Switches in Policy and Volatility

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<td>$\sigma$</td>
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<td>[2.377,3.138]</td>
<td>[2.380,3.153]</td>
<td>[2.586,3.255]</td>
<td>[1.762,3.387]</td>
</tr>
<tr>
<td>$\alpha$</td>
<td>[0.703,0.758]</td>
<td>[0.713,0.776]</td>
<td>[0.724,0.785]</td>
<td>[0.725,0.777]</td>
<td>[0.756,0.808]</td>
</tr>
<tr>
<td>$\zeta$</td>
<td>[0.080,0.288]</td>
<td>[0.021,0.110]</td>
<td>[0.027,0.126]</td>
<td>[0.034,0.150]</td>
<td>[0.054,0.185]</td>
</tr>
<tr>
<td>$\theta$</td>
<td>[0.287,0.715]</td>
<td>[0.588,0.924]</td>
<td>[0.603,0.929]</td>
<td>[0.507,0.834]</td>
<td>[0.200,0.842]</td>
</tr>
<tr>
<td>$\varphi$</td>
<td>[2.021,2.822]</td>
<td>[2.035,2.869]</td>
<td>[2.036,2.861]</td>
<td>[1.857,2.062]</td>
<td>[0.986,1.986]</td>
</tr>
<tr>
<td></td>
<td>Shock Processes</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\rho^2$</td>
<td>[0.827,0.999]</td>
<td>[0.884,0.950]</td>
<td>[0.896,0.962]</td>
<td>[0.917,0.954]</td>
<td>[0.897,0.941]</td>
</tr>
<tr>
<td>$\mu^2$</td>
<td>[0.947,0.978]</td>
<td>[0.240,0.741]</td>
<td>[0.250,0.748]</td>
<td>[0.945,0.978]</td>
<td>[0.948,0.979]</td>
</tr>
<tr>
<td>$\rho^2$</td>
<td>[0.232,0.347]</td>
<td>0.357</td>
<td>0.233</td>
<td>0.245</td>
<td></td>
</tr>
<tr>
<td>$\sigma^2_{\xi(s=1)}$</td>
<td>[0.345,0.798]</td>
<td>[0.435,0.728]</td>
<td>[0.316,0.606]</td>
<td>[0.338,0.673]</td>
<td>[0.627,1.578]</td>
</tr>
<tr>
<td>$\sigma^2_{\zeta(s=2)}$</td>
<td>[0.624,1.424]</td>
<td>[0.584,0.923]</td>
<td>[0.760,1.424]</td>
<td>[0.657,1.352]</td>
<td>[0.760,2.013]</td>
</tr>
<tr>
<td>$\sigma^2_{\mu(s=1)}$</td>
<td>[0.148,0.261]</td>
<td>[0.131,0.728]</td>
<td>[0.138,0.492]</td>
<td>[1.247,0.213]</td>
<td>[0.169,0.317]</td>
</tr>
<tr>
<td>$\sigma^2_{\mu(s=2)}$</td>
<td>[0.357,0.453]</td>
<td>[0.286,0.923]</td>
<td>[0.288,0.987]</td>
<td>[4.042,7.256]</td>
<td>[0.541,1.011]</td>
</tr>
<tr>
<td>$\sigma^2_{\zeta(s=1)}$</td>
<td>[0.290,0.390]</td>
<td>[0.304,0.417]</td>
<td>[0.314,0.446]</td>
<td>[0.300,0.426]</td>
<td>[0.323,0.440]</td>
</tr>
<tr>
<td>$\sigma^2_{\zeta(s=2)}$</td>
<td>[0.610,0.824]</td>
<td>[0.582,0.808]</td>
<td>[0.580,0.815]</td>
<td>[0.686,1.006]</td>
<td>[0.638,0.888]</td>
</tr>
<tr>
<td>$\sigma^2_{\gamma(s=1)}$</td>
<td>--</td>
<td>0.118</td>
<td>0.123</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>$\sigma^2_{\gamma(s=2)}$</td>
<td>--</td>
<td>0.318</td>
<td>0.332</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td></td>
<td>Data Means</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\gamma_A$</td>
<td>[0.533,1.519]</td>
<td>[0.494,0.968]</td>
<td>[0.385,1.035]</td>
<td>[0.731,1.929]</td>
<td>[0.595,1.687]</td>
</tr>
<tr>
<td>$\pi_A^{(s=1)}$</td>
<td>2.794</td>
<td>3.027</td>
<td>3.205</td>
<td>1.872</td>
<td>2.589</td>
</tr>
<tr>
<td>$\pi_A^{(s=2)}$</td>
<td>[2.093,3.461]</td>
<td>[2.613,3.453]</td>
<td>[2.193,4.187]</td>
<td>[1.485,2.253]</td>
<td>[2.006,3.165]</td>
</tr>
<tr>
<td>$\gamma_Q$</td>
<td>0.510</td>
<td>0.543</td>
<td>0.511</td>
<td>0.665</td>
<td>0.532</td>
</tr>
</tbody>
</table>

continued on the next page
### Table 2: Estimation Results - Switches in Policy and Volatility – continued

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Discretion</th>
<th>Rule - Parameters</th>
<th>Rule - Target</th>
<th>Commitment</th>
<th>Quasi-Commitment</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \psi )</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>( \rho^R_{(S=1)} )</td>
<td>–</td>
<td>0.820</td>
<td>0.821</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>( \rho^R_{(S=2)} )</td>
<td>–</td>
<td>0.769</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>( \psi_1(S=1) )</td>
<td>–</td>
<td>2.362</td>
<td>1.307</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>( \psi_1(S=2) )</td>
<td>–</td>
<td>0.933</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>( \psi_2(S=1) )</td>
<td>–</td>
<td>0.478</td>
<td>0.346</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>( \psi_2(S=2) )</td>
<td>–</td>
<td>0.292</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>( \omega_1 )</td>
<td>0.399</td>
<td>–</td>
<td>–</td>
<td>0.608</td>
<td>0.758</td>
</tr>
<tr>
<td>( \omega_2 )</td>
<td>0.676</td>
<td>–</td>
<td>–</td>
<td>0.626</td>
<td>0.846</td>
</tr>
<tr>
<td>( \omega_\pi(S=1) )</td>
<td>1</td>
<td>–</td>
<td>–</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>( \omega_\pi(S=2) )</td>
<td>0.477</td>
<td>–</td>
<td>–</td>
<td>0.625</td>
<td>–</td>
</tr>
</tbody>
</table>

### Markov Transition Probabilities

| \( P_{11} \) | 0.897      | 0.936            | 0.952         | 0.928      | –               |
|\( P_{22} \) | 0.886      | 0.919            | 0.901         | 0.905      | –               |
| \( q_{11} \) | 0.928      | 0.944            | 0.948         | 0.939      | 0.916           |
| \( q_{22} \) | 0.953      | 0.916            | 0.913         | 0.960      | 0.955           |

| \( z_{11} \) | 0.852      | [0.789, 0.918]   | –             | –          | –               |
| \( z_{22} \) | 0.957      | [0.928, 0.987]   | –             | –          | –               |

### Log Marginal Data Densities and Bayes Factors

| Geweke (1999) | \(-549.565\) | \(-564.718\) | \(-565.303\) | \(-591.761\) | \(-596.582\) |
| (1.00)        | (3.81e+6)   | (6.64e+6)    | (2.12e+20)   | (2.63e+20)   | (2.57e+20)    |
| Sims et al. (2008) | \(-549.799\) | \(-564.959\) | \(-565.684\) | \(-592.028\) | \(-596.794\) |
| (1.00)        | (3.84e+6)   | (7.92e+6)    | (2.19e+18)   | (2.57e+20)   | (2.57e+20)    |

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 4: Optimal Target Weights Across Different Social Welfare Functions

<table>
<thead>
<tr>
<th>Target</th>
<th>Micro. Weights</th>
<th>Est. Weights</th>
<th>Revealed Preference Weights</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inflation</td>
<td>0.13E+13</td>
<td>6.99</td>
<td>1.00</td>
</tr>
<tr>
<td>Nominal Income Growth</td>
<td>3.9797</td>
<td>1.71</td>
<td>0.63</td>
</tr>
<tr>
<td>Speed Limit</td>
<td>0.1512</td>
<td>10.10</td>
<td>182.61</td>
</tr>
<tr>
<td>Price Level</td>
<td>0.3E+15</td>
<td>0.24</td>
<td>0.018</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Regime: (conservatism, volatility)</th>
<th>Output</th>
<th>Inflation</th>
<th>Interest Rate</th>
<th>Welfare Cost (est. weights)</th>
<th>Welfare Cost (micro. weights)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Discretion</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(low, high)</td>
<td>0.215</td>
<td>3.574</td>
<td>2.518</td>
<td>6.315</td>
<td>1.52%</td>
</tr>
<tr>
<td></td>
<td>[0.146,0.329]</td>
<td>[2.495,5.603]</td>
<td>[1.575,4.379]</td>
<td>[3.485,12.82]</td>
<td>[1.02%,2.356%]</td>
</tr>
<tr>
<td>(high, high)</td>
<td>0.2154</td>
<td>1.169</td>
<td>0.799</td>
<td>6.081</td>
<td>0.62%</td>
</tr>
<tr>
<td></td>
<td>[0.149,0.332]</td>
<td>[0.832,1.680]</td>
<td>[0.550,1.233]</td>
<td>[3.260,12.516]</td>
<td>[0.40%,0.97%]</td>
</tr>
<tr>
<td>(low, low)</td>
<td>0.096</td>
<td>1.591</td>
<td>1.005</td>
<td>1.806</td>
<td>0.36%</td>
</tr>
<tr>
<td></td>
<td>[0.066,0.143]</td>
<td>[1.108,2.504]</td>
<td>[0.612,1.796]</td>
<td>[0.948,3.931]</td>
<td>[0.23%,0.60%]</td>
</tr>
<tr>
<td>(high, low)</td>
<td>0.145</td>
<td>0.030</td>
<td>0.518</td>
<td>2.9878</td>
<td>0.10%</td>
</tr>
<tr>
<td></td>
<td>[0.105,0.229]</td>
<td>[0.021,0.041]</td>
<td>[0.435,0.622]</td>
<td>[1.420,6.6445]</td>
<td>[0.06%,0.19%]</td>
</tr>
<tr>
<td>Commitment</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(low, high)</td>
<td>0.237</td>
<td>0.075</td>
<td>0.727</td>
<td>5.141</td>
<td>0.20%</td>
</tr>
<tr>
<td></td>
<td>[0.168,0.355]</td>
<td>[0.053,0.110]</td>
<td>[0.595,0.901]</td>
<td>[2.473,11.429]</td>
<td>[0.13%,0.35%]</td>
</tr>
<tr>
<td>(high, high)</td>
<td>0.232</td>
<td>0.023</td>
<td>0.683</td>
<td>5.189</td>
<td>0.16%</td>
</tr>
<tr>
<td></td>
<td>[0.164,0.351]</td>
<td>[0.016,0.034]</td>
<td>[0.560,0.839]</td>
<td>[2.516,11.49]</td>
<td>[0.09%,0.30%]</td>
</tr>
<tr>
<td>(low, low)</td>
<td>0.101</td>
<td>0.037</td>
<td>0.404</td>
<td>1.546</td>
<td>0.06%</td>
</tr>
<tr>
<td></td>
<td>[0.072,0.150]</td>
<td>[0.026,0.058]</td>
<td>[0.327,0.498]</td>
<td>[0.727,3.585]</td>
<td>[0.04%,0.11%]</td>
</tr>
<tr>
<td>(high, low)</td>
<td>0.095</td>
<td>0.012</td>
<td>0.379</td>
<td>1.560</td>
<td>0.05%</td>
</tr>
<tr>
<td></td>
<td>[0.068,0.145]</td>
<td>[0.008,0.017]</td>
<td>[0.311,0.462]</td>
<td>[0.739,3.604]</td>
<td>[0.03%,0.09%]</td>
</tr>
</tbody>
</table>

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 (18). The welfare costs using micro-founded weights is based on equation (12), 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 5: Unconditional Variances and Welfare under Alternative Delegation Schemes

<table>
<thead>
<tr>
<th>Target</th>
<th>Output</th>
<th>Inflation</th>
<th>Interest Rate</th>
<th>Welfare Cost (est. weights)</th>
<th>Welfare Cost (micro. weights)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>High Volatility</td>
<td></td>
</tr>
<tr>
<td>Inflation</td>
<td>0.230</td>
<td>0.037</td>
<td>0.358</td>
<td>5.291</td>
<td>0.143%</td>
</tr>
<tr>
<td>Nominal Income</td>
<td>0.267</td>
<td>0.268</td>
<td>0.392</td>
<td>5.694</td>
<td>0.296%</td>
</tr>
<tr>
<td>Speed Limit</td>
<td>0.206</td>
<td>0.011</td>
<td>0.447</td>
<td>5.302</td>
<td>0.129%</td>
</tr>
<tr>
<td>Price Level</td>
<td>0.220</td>
<td>0.041</td>
<td>0.354</td>
<td>5.278</td>
<td>0.145%</td>
</tr>
<tr>
<td>Commitment</td>
<td>0.232</td>
<td>0.023</td>
<td>0.683</td>
<td>5.189</td>
<td>0.16%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Low Volatility</td>
<td></td>
</tr>
<tr>
<td>Inflation</td>
<td>0.091</td>
<td>0.017</td>
<td>0.192</td>
<td>1.588</td>
<td>0.04%</td>
</tr>
<tr>
<td>Nominal Income</td>
<td>0.112</td>
<td>0.124</td>
<td>0.191</td>
<td>1.676</td>
<td>0.08%</td>
</tr>
<tr>
<td>Speed Limit</td>
<td>0.081</td>
<td>0.004</td>
<td>0.247</td>
<td>1.594</td>
<td>0.04%</td>
</tr>
<tr>
<td>Price Level</td>
<td>0.091</td>
<td>0.019</td>
<td>0.190</td>
<td>1.585</td>
<td>0.04%</td>
</tr>
<tr>
<td>Commitment</td>
<td>0.095</td>
<td>0.012</td>
<td>0.379</td>
<td>1.560</td>
<td>0.05%</td>
</tr>
</tbody>
</table>

### Table 6: Unconditional Variances and Welfare under Alternative Delegation Schemes

<table>
<thead>
<tr>
<th>Policy Target</th>
<th>Output</th>
<th>Inflation</th>
<th>Interest Rate</th>
<th>Welfare Cost (revealed weights)</th>
<th>Welfare Cost (micro. weights)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>High Volatility</td>
<td></td>
</tr>
<tr>
<td>Inflation</td>
<td>0.215</td>
<td>1.169</td>
<td>0.799</td>
<td>5.202</td>
<td>0.618%</td>
</tr>
<tr>
<td>Nominal Income</td>
<td>0.225</td>
<td>1.424</td>
<td>0.981</td>
<td>5.281</td>
<td>0.729%</td>
</tr>
<tr>
<td>Speed Limit</td>
<td>0.008</td>
<td>0.042</td>
<td>0.727</td>
<td>5.175</td>
<td>0.133%</td>
</tr>
<tr>
<td>Price Level</td>
<td>0.237</td>
<td>0.114</td>
<td>0.650</td>
<td>5.083</td>
<td>0.222%</td>
</tr>
<tr>
<td>Commitment</td>
<td>0.255</td>
<td>0.436</td>
<td>0.740</td>
<td>5.044</td>
<td>0.420%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Low Volatility</td>
<td></td>
</tr>
<tr>
<td>Inflation</td>
<td>0.090</td>
<td>0.535</td>
<td>0.323</td>
<td>1.559</td>
<td>0.159%</td>
</tr>
<tr>
<td>Nominal Income</td>
<td>0.096</td>
<td>0.644</td>
<td>0.396</td>
<td>1.578</td>
<td>0.182%</td>
</tr>
<tr>
<td>Speed Limit</td>
<td>0.0033</td>
<td>0.017</td>
<td>0.362</td>
<td>1.573</td>
<td>0.036%</td>
</tr>
<tr>
<td>Price Level</td>
<td>0.101</td>
<td>0.058</td>
<td>0.359</td>
<td>1.530</td>
<td>0.065%</td>
</tr>
<tr>
<td>Commitment</td>
<td>0.117</td>
<td>0.213</td>
<td>0.398</td>
<td>1.520</td>
<td>0.118%</td>
</tr>
</tbody>
</table>

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