UNIVERSITY OF EXETER

Economics Department Discussion Papers Series

ISSN 1473 – 3307

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Paper number 11/08

Degree of Policy Precommitment in the UK: An Empirical Investigation of Monetary and Fiscal Policy Interactions*

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June 15, 2011

Abstract

This paper investigates the conduct of monetary and fiscal policy in the UK in the period of the Bank of England independence and before the start of the quantitative easing. Using a simple DSGE New Keynesian model of non-cooperative monetary and fiscal policy interactions under the fiscal intra-period leadership we demonstrate that the past policy in the UK is better explained as following optimal policy under discretion than under commitment. We estimate policy objectives of both policy makers, and derive implied policy rules.

Key Words: Monetary and Fiscal Policy, Commitment, Discretion, Macroeconomic Stabilisation, Bayesian Estimation

JEL Reference Number: E52, E61, E63

*This paper represents the views and analysis of the authors and does not represent the views of the Department for Work and Pensions. All errors remain ours.

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1 Introduction

It has long been known in the literature on monetary policy that if policy makers can precommit to a stabilization plan then they can achieve a significant welfare gain. This is relative to the case of discretionary policy and in an environment where the current decisions of the forward-looking private sector are largely determined by their expectations.[1]

A policy maker who can commit chooses a policy plan once and then follows this policy at all dates in the future. This policy is the best from today's perspective, provided that the precommitment is credible. However, the policy is time-inconsistent and with the passage of time the policy maker will have an incentive to renege.

In contrast, a discretionary policy is time-consistent and credible. It is known that the policy maker re-optimizes every period. In the resulting equilibrium, given an opportunity to renege on the expected policy for the next period, the policy maker will find it optimal to choose the same policy for that period.

A credible commitment policy is able to take advantage of the forward-looking behaviour of the agents, by allowing them to understand how the policy will react to all circumstances in future periods. It can be formulated in terms of a contingent *inter-temporal plan*, and the plan is linked to the initial date and has clear relations between consequent periods. This reflects the ability of the policy maker to manipulate the expectations in a desired way and convince the private sector to coordinate at the best possible intertemporal outcome, linked to the date of precommitment. In contrast, a discretionary policy can rather be described as a set of *intra-temporal contingent rules*; the forward-looking private sector recognizes this feature and also reacts optimally, but it reacts only to the current state, as past promises are ignored.

Although the different properties of these two benchmark policies having been known for decades, the issue of practical implementation of such policies remains controversial. Most discussions concern *monetary policy.* Although there is little doubt that major central banks are able to precommit to a target – as for example an inflation target – the way they actually manage the *expectations of policies* to achieve the target remains underexplored. The key problem with acceptance of the theoretical concept of commitment policy as a practical option has always been its time-inconsistency. It is well understood that the policy maker will have an incentive to renege at *every* consequent period. This is because the private sector will have part of the 'work' done by setting its expectations in a particular way, and exploiting these expectations would be bene-

[1] See Kydland and Prescott (1977), Currie and Levine (1993), Woodford (2003a) among many others.

ficial from that perspective. Also, it is because the policy maker may have some additional and sudden 'distractions', like the task to maintain financial stability. Issues with financial stability may require sudden monetary loosening regardless of the inflation record at the time.

Despite the well understood difficulties with the ability of a central bank to precommit to a policy plan, the statements of major central banks about their practices differ widely. The early statements do not suggest that banks precommit to a plan which is chosen once and forever. In particular, after the Bank of England gained its independence King (1997) proclaimed a regime of 'constrained discretion'. In these statements the word 'discretion' , which does not typically assume an ability to manipulate expectations over time, has rather been used to acknowledge inevitable 'distractions'. On the other hand, the word 'constrained' was meant to mean that the 'distractions' will not dominate. The Bank of England would, therefore, not pursue a short-term gain at the expense of mid-term inflation stability. This was meant to improve the credibility of the policy in eyes of the private sector. Nothing in King (1997) suggests that the word 'discretion' is meant to exclude the possibility that the Bank of England would not be able to manipulate the private sector's expectations, and use information from longer period of time, rather than just within the current period. Bernanke and Mishkin (1997) give similar arguments to describe the US monetary policy as discretionary. Givens (2011) and Coroneo et al. (2011) estimate that the Volker-Bernanke period in the US is best described by the discretionary monetary regime.

More recently, the statements of some European central banks have either described their current monetary policy as policy under commitment, or come very close to doing so. The intertemporal feature of a commitment policy is being communicated as a 'predictable response pattern'. See Bergo (2007) for the view of the Norges Bank and Svensson (2009) for policy recommendations for the Riksbank to follow in the footsteps of Norges Bank by generating policy projections as optimal projections. Adolfson et al. (2009) also find that the past policy of Riksbank is better explained as optimal policy under commitment than as simple rules.

The recent documents may imply that the Bank of England takes a similar view on the issue (Tucker (2006)). A clear target and a public commitment to anchor inflation expectations in line with this target, together with being understood to be willing to do whatever is necessary to achieve this goal, not just in the current period but in all periods, is critical to achieving credibility. Once credibility is achieved, a central bank that wants to maintain the credibility of its promises would then clearly recognize that reneging on past promises would lead to a loss of credibility. One might interpret this statement that, in effect, the Bank of England was able to *precommit to the policy* and then chose not to renege on its previously chosen *intertemporal* policy. It is an empirical question, however, whether the Bank of England was able to manage the private sector's expectations as it would do if it did not have an opportunity to renege at all.

Fiscal policy arrangements are much less discussed in the literature, although they may play a very important role in identifying the monetary policy regime, see e.g. Leeper (1991). Partly because of institutional arrangements, it is believed that fiscal policy is too inflexible to be used for active stabilization. However, recent developments in the UK, in particular a recent episode of using Value Added Tax as a stabilization device, has shown that there might be a more active role for fiscal policy. The establishment of the Office of Budget Responsibility marks another step to greater fiscal flexibility in the UK.[2] This suggests that a more focussed discussion on the institutional design of stabilizing fiscal policy may not be too far into the future.

In this paper we investigate empirically the monetary and fiscal policy interactions in the UK. We investigate whether a model of interactions under commitment or discretion fits the data better. We use data from the period after the Bank of England was granted independence in 1997 up to and including the second quarter of 2008, just before the main impact of the current recession on the world economy and the consequent regime of quantitative easing in the UK. This is a period when the monetary authorities can be described as conducting inflation targeting and fiscal policy was conducted by the same government with relatively stable targets. In choosing this period so we implicitly assume that if the authorities could precommit to a new policy plan, and the point of precommitment would be linked to the new government taking the office in 1997.

Our model is a simple version of the Gali and Monacelli (2005, 2008) model of a small open economy, which is extended to include fiscal policy. Following Lubik and Schorfheide (2007) we keep the model simple and stylised as this can nevertheless produce sufficient identifying restrictions to estimate policy rules. We use the theoretical framework of *non-cooperative* monetary and fiscal discretionary interactions, as in Blake and Kirsanova (2011) and Fragetta and Kirsanova (2010). We also develop an appropriate theoretical framework for non-cooperative commitment. We then use Bayesian estimation to obtain the policy objectives under two alternative assumptions about the policy makers' degree of precommitment.

As in Svensson (2003), Dennis (2006), Ilbas (2011) and Givens (2011) we directly estimate the relative weights of the authority's objective loss function. This allows us to examine observed economic outcomes within an optimising policy framework.[3]

Our results demonstrate that the monetary and fiscal policy regime in the UK under the

[2] See Osborne (2008), see also Wyplosz (2005) and Kirsanova et al. (2006) for more theoretical approach.

[3] Monetary policy in the US under the assumption of discretionary regime was studied in Dennis (2000), Dennis (2004), Castelnuovo (2006).

assumption of fiscal leadership can best be described by a regime of optimal policy under discretion. The probability that the actual data was generated by a model with optimal commitment policy, rather than by a model with optimal discretionary policy, is about 1.5%. We find that the discretionary monetary policy maker has output stabilization target with higher relative weight than socially optimal. We do not find a strong debt stabilization target for fiscal authorities. We also find a considerable smoothing of both policy instruments.

Our results can be compared with those in Givens (2011), who identifies the monetary policy regime in the US as a discretionary policy. Relative to this work, we use a different model, with different definition of the output gap, and without assuming additional inflation inertia and habit persistence. The inertia in our model is generated by slow debt adjustment that has implications for the conduct of fiscal and monetary policy. We also impose fiscal solvency constraint, which serves as an important identifying restriction for both fiscal and monetary policy reactions.[4]

This paper is organized as follows. In the next section we outline the model and describe policy interactions under commitment and discretion. Section 3 explains the theoretical framework for the two policy regimes. Section 4 explains the empirical methodology, the choice of priors and the data set. The results are discussed in section 5 and section 6 concludes.

2 The Model

We use a version of the Gali and Monacelli (2005, 2008) model, as in Lubik and Schorfheide (2007), modified to include fiscal policy.

2.1 Private Sector

The economy is populated by a representative household, by a unit-continuum of monopolistically competitive firms, and by two policy makers: the government and the central bank.

The household is infinitely lived and maximizes the expected utility:

$$W = \mathcal{E}_t \sum_{t=0}^{\infty} \beta^t \left(\frac{C_t^{1-\sigma}}{1-\sigma} + \zeta \frac{G_t^{1-\sigma}}{1-\sigma} - \frac{N_t^{1+\varphi}}{1+\varphi} \right) \tag{1}$$

subject to a standard intertemporal budget constraint. Here C_t is private consumption, G_t is government spending and N_t is labour supplied. Parameter β is the household discount rate, φ is the labour elasticity and $1/\sigma$ is the intertemporal elasticity of substitution. ζ is a relative importance of consumption of public goods. After the linearization of the first order conditions and

[4] In a very different empirical framework, using set-identification methods, Coroneo et al. (2011) discriminate against commitment monetary policy regime in the US.

substituting consumption out using the national income identity and the risk sharing condition, we obtain an open economy IS curve:

$$y_t = \mathcal{E}_t y_{t+1} - \frac{1}{\sigma_\alpha}\left(i_t - \mathcal{E}_t \pi_{Ht+1}\right) - \mathcal{E}_t g_{t+1} + g_t + s_y y_t^*. \tag{2}$$

Where Y_t is aggregate output and $y_t = \ln(Y_t)$, government spending $g_t = \frac{1-\theta}{\theta}\ln(\frac{G_t}{Y_t})$, nominal interest rate $i_t = \ln(R_t)$, P_{Ht} is domestic price level and domestic inflation $\pi_{Ht} = \ln\left(P_{Ht}/P_{Ht-1}\right)$. The import component of CPI inflation was substituted out using the risk sharing condition. y_t^* is exogenous world output shock. Parameter θ denotes steady state consumption to output ratio. Parameter $\sigma_\alpha = \sigma/((1-\alpha)+\alpha\omega)$ where $\omega = \sigma\eta + (1-\alpha)(\sigma\eta - 1)$, parameter η is the elasticity of substitution between foreign and domestic goods and $s_y = \alpha(1-\omega)\left(1-\rho_y\right)$, and α is the openness of the economy.

The monopolistically competitive firms set prices optimally, but they are locked in Calvo (1983) -type contracts. Aggregation across prices leads to an open-economy New Keynesian Phillips curve after linearizing about a zero-inflation nonstochastic steady state:

$$\pi_{Ht} = \beta\mathcal{E}_t\pi_{Ht+1} + \lambda\left(\left(\sigma_\alpha + \varphi\right)y_t - \sigma_\alpha g_t + \left(\sigma - \sigma_\alpha\right)y_t^* - \left(1+\varphi\right)a_t\right) + \varepsilon_t^\pi. \tag{3}$$

The slope coefficient λ is a function of the household discount rate and of the length of fixed-price contracts: $\lambda = (1-\beta\gamma)(1-\gamma)/\gamma$ where γ is the probability that the price remains unchanged. Here $a_t = \log A_t$ is a technology shock and ε_t^π is a cost push shock, which can appear in the system because of variable mark up, see e.g. Beetsma and Jensen (2004). (And it also includes all other disturbances to marginal costs that are not captured by our model.)

We assume that all public debt consists of riskless one-period bonds. The nominal value $\mathcal{B}_t$ of end-of-period public debt then evolves according to a law of motion:

$$\mathcal{B}_t = \left(1 + i_{t-1}\right)\mathcal{B}_{t-1} + P_{Ht}G_t - \tau P_{Ht}Y_t + T \tag{4}$$

where τ is constant share of national product Y_t that is collected by the government in period t. The time-invariant term T collects all steady state lump-sum subsidies and taxes. For analytical convenience we introduce the real value of debt at maturity $B_t = (1+i_{t-1})\mathcal{B}_{t-1}/P_{Ht-1}$, observed at the beginning of period t, so that (4) becomes

$$B_{t+1} = \left(1+i_t\right)\left(B_t\frac{P_{t-1}}{P_t} - \tau Y_t + G_t + T\right). \tag{5}$$

Log-linearizing (5) yields

$$b_{t+1} = \chi i_t + \frac{1}{\beta}\left(b_t - \chi\pi_{Ht} + \theta g_t + \left(1-\theta-\tau\right)y_t\right) \tag{6}$$

where $b_t = \chi \ln(B_t)$, χ is the steady state debt to GDP ratio.

A private sector rational expectations equilibrium consists of plan $\{y_t, \pi_{Ht}, b_t\}$ satisfying equations (2)-(6), given the policy $\{i_t, g_t\}$, the exogenous processes $\{\varepsilon_t^\pi, a_t, y_t^*\}$, and initial conditions b_0.

2.2 Policy

2.2.1 Social Welfare

The monetary policy maker (the central bank, uses the nominal interest rate, i_t, as its instrument, and the fiscal policy maker (the government) uses spending, g_t.[5]

If the policy makers are benevolent, then the maximization of aggregated household utility (1) implies the following optimization problem for each of them: each policy maker minimizes the discounted sum of all future losses:

$$W = (1-\beta)\,\mathcal{E}_t \sum_{t=0}^{\infty} \beta^t W_t^S \tag{7}$$

where, for our model of a small open economy, the intra-period term can be written as:

$$W_t^S = \pi_{Ht}^2 + \Phi_y\,(y_t - y_t^e)^2 + \Phi_{yg}\,(y_t - y_t^e)\,(g_t - g_t^e) + \Phi_g\,(g_t - g_t^e)^2\,, \tag{8}$$

where terms independent of policy and terms of higher order are ignored.[6] Here y_t^e and g_t^e are output and spending in the efficient equilibrium (in the absence of nominal rigidities and distortionary cost push shocks) which are defined in the Online Appendix. The weights Φ are functions of the structural parameters of the model. They are re-scaled so that the coefficient on inflation variability is normalized to one.

2.2.2 Policy Objectives

It is often suggested that realistic policy makers are not benevolent, and this implies additional policy objectives to those suggested by formula (8) as well as distorted weights on social objectives.

There are some theoretical reasons for introducing the additional objectives and for distorting social weights of a *discretionary* policy maker. First, the monetary policy maker which acts under discretion can reduce the 'stabilization bias' if he adopts an additional interest rate smoothing target: the policy will become 'history-dependent' and approximate a policy under commitment

[5] We follow Gali and Monacelli (2005, 2008) in the choice of fiscal instrument; also, empirical evidence in Favero and Monacelli (2005), Taylor (2000) and Auerbach (2002), for example, suggests that government spending does move.

[6] See Appendix A for coefficients. All derivations are given in Fragetta and Kirsanova (2010).

better (Woodford (2003b)). Following Barro and Gordon (1983) famous result, Clarida et al. (1999) show that the discretionary monetary authority which puts higher than socially optimal weight on inflation stabilization target can achieve the same level of welfare as under the optimal precommitment-to-rules policy.[7] Second, different institutional restrictions can also be captured by introducing additional targets. For example, fiscal policy is relatively inflexible, or 'slow', and current period spending decisions are often based on past period allocations, as it might be easier to pass parliamentary scrutiny. We can term such fiscal behaviour as 'habits', and assume that the fiscal policy maker faces an additional penalty if he changes spending by a large amount relative to the past period spending. Of course, the optimizing framework may not explain the full extent of the observed policy inertia. Finally, the policy maker may not be able to 'compute' microfounded welfare for complex models.

Therefore, in our empirical specification we shall not assume that the actual authorities use micro-founded weights on inflation, output and government spending in their objectives. We allow for additional policy objectives, such as instrument smoothing and a debt target for the fiscal authority, that are not present in the social objectives. We check whether our estimates of these relative weights are consistent with social weights whenever we include socially justified targets.

We assume that both monetary and fiscal authorities act *non-cooperatively* in order to stabilize the economy against shocks. Formally, the monetary authority chooses the interest rate to minimize the intertemporal welfare loss with flow objectives in the form of

$$W_t^M = \pi_{Ht}^2 + \Phi_{MY}\left(y_t - y_t^e\right)^2 + \Phi_{MYG}\left(y_t - y_t^e\right)\left(g_t - g_t^e\right) + \Phi_{MG}\left(g_t - g_t^e\right)^2 + \Phi_{\Delta I}\left(\Delta i_t\right)^2, \quad (9)$$

subject to system (2)-(6) and fiscal authority chooses spending to minimize the intertemporal welfare loss with flow objectives in the form of

$$W_t^F = \pi_{Ht}^2 + \Phi_{FY}\left(y_t - y_t^e\right)^2 + \Phi_{FYG}\left(y_t - y_t^e\right)\left(g_t - g_t^e\right) + \Phi_{FG}\left(g_t - g_t^e\right)^2 + \Phi_{\Delta G}\left(\Delta g_t\right)^2 + \Phi_{FB} b_t^2, \quad (10)$$

subject to the same system. Both authorities have the same discount factor which is the household discount rate.

2.2.3 Strategic Interactions

We assume that the fiscal policy maker acts as an intra-period leader and the monetary authority acts as an intra-period follower. Fragetta and Kirsanova (2010) show that the assumption of

[7] For other 'policy delegation' proposals see e.g. Svensson (1997), Vestin (2006), Walsh (2003) and Woodford (2003b).

fiscal leadership gives the best fit for the UK when compared with a regime of simultaneous moves under discretion. This assumption implies that the leader, the fiscal authority, knows the reaction function of the monetary authority and takes it into account when formulating policy. This has important consequences for the macroeconomic stabilization of the economy in response to shocks. If the fiscal authority is able to conduct itself as a Stackelberg leader, then it will willingly allow the monetary authority to carry out almost all of the required macroeconomic stabilization, see Blake and Kirsanova (2011). We also retain the assumption of fiscal leadership for the case of commitment.

3 Theoretical Framework

Our model belongs to the class of nonsingular linear stochastic rational expectations models of the type described by Blanchard and Kahn (1980), augmented by a vector of control instruments.

Notation 1 *We label the two policy makers as leader (L) and follower (F), and denote them with index i, $i \in \{L, F\}$. In our case the leader is the fiscal policy maker and the follower is the monetary policy maker.*

The evolution of the economy is explained by the following system:

$$\begin{bmatrix} \mathsf{y}_{t+1} \\ \mathcal{E}_t \mathsf{x}_{t+1} \end{bmatrix} = \begin{bmatrix} A_{11} & A_{12} \\ A_{21} & A_{22} \end{bmatrix} \begin{bmatrix} \mathsf{y}_t \\ \mathsf{x}_t \end{bmatrix} + \begin{bmatrix} B_{11} & B_{12} \\ B_{21} & B_{22} \end{bmatrix} \begin{bmatrix} \mathsf{u}_t^L \\ \mathsf{u}_t^F \end{bmatrix} + \begin{bmatrix} \epsilon_{t+1} \\ 0 \end{bmatrix}. \tag{11}$$

where y_t is a vector of predetermined variables with initial conditions y_0 given, $\mathsf{y}_t = [a_t, y_t^*, \varepsilon_t^\pi, b_t]'$, x_t is a vector of non-predetermined (or jump) variables, $\mathsf{x}_t = [\pi_{Ht}, x_t]'$ where $x_t \equiv y_t - g_t$. u_t^F and u_t^L are the two vectors of policy instruments of the two policy makers, named F and L. $\mathsf{u}_t^F = i_t$ and $\mathsf{u}_t^L = g_t$ in the model. ϵ_t is a vector of i.i.d. shocks.

Each of the two policy makers has the following loss functions:

$$J_t^j = \frac{1}{2} \mathcal{E}_t \sum_{s=t}^{\infty} \beta^{s-t} (G_s' \mathcal{Q}^j G_s), \tag{12}$$

where $j = \{L, F\}$ and G_s^j is a vector of goal variables of policy maker i; which is a linear function of state variables and instruments, $G_s^j = \mathcal{C}^j \left[\mathsf{y}_s', \mathsf{x}_s', \mathsf{u}_s^{L\prime}, \mathsf{u}_s^{F\prime} \right]'$.

Commitment policy means that each policy maker is able to commit, with full credibility, to a policy *plan* (Currie and Levine (1993)). Thus, the policy plan has to specify the desired levels of the target variables (e.g. inflation, the output gap, etc.) at all current and future dates and states of nature. When we bring it down to empirical tests we should either choose the exact date at which the precommitment was made, or use the timeless perspective policy (Woodford (2003a)) and consider our observations as a subset, strictly within a larger set, which contains a longer series of observations with initial commitment.[8] We discuss our empirical strategy in Section 4.2.

Assumption 1 *At each time t the follower observes the current decision of the leader u_t^L. The private sector observes both decisions u_t^L and u_t^F.*

Assumption 2 *At any time t both policy makers know Assumption 1.*

Problem 2 (Leadership under commitment) *Under commitment the follower solves*

$$\min_{\{u_s^F\}_{s=t}^{\infty}} \frac{1}{2}\mathcal{E}_t \sum_{s=t}^{\infty} \beta^{s-t}(G_s^{F\prime}\mathcal{Q}^F G_s^F) \tag{13}$$

subject to constraint (11).

The leader solves

$$\min_{\{u_t^L\}_{s=t}^{\infty}} \frac{1}{2}\mathcal{E}_t \sum_{s=t}^{\infty} \beta^{s-t}(G_s^{L\prime}\mathcal{Q}^L G_s^L) \tag{14}$$

subject to constraint (11) and to the system of first order conditions of the follower's optimization problem.

The follower observes policy of the leader and reacts to it. The leader knows the follower reacts to its policy and is able to exploit it.

Discretionary policy means that the policy maker treats its optimal policy problem, as described above, as one of 'sequential optimization', i.e. without committing to any future course of action it makes the decision that is optimal within that period only.

Assumption 3 *Suppose at time t the private sector and the policy makers only responds to the current state*

$$\begin{bmatrix} \mathsf{x}_t \\ \mathsf{u}_t^L \\ \mathsf{u}_t^F \end{bmatrix} = -\begin{bmatrix} \mathsf{N}^d \\ F_1^L \\ F_2^F \end{bmatrix} \mathsf{y}_t \tag{15}$$

[8]The timeless perspective policy assumes that consequent policymakers follow the same policy as their predecessors, i.e. the point of precommitment was a long time ago.

Assumption 4 *At each time t the private sector observes the current policy decisions* $\mathsf{u}_t^L, \mathsf{u}_t^F$ *and expects that future policy makers will reoptimize, and will apply the same decision process and implement decision* $[F_1^{L\prime}, F_2^{F\prime}]'$*. At each time t the follower observes the current policy decision of the leader* u_t^L *and expects that future leader will reoptimize, and will apply the same decision process and implement decision* F_1^L*.*

Problem 3 (Leadership under discretion) *Under discretion the follower solves*

$$\min_{u_t^F} \frac{1}{2}\mathcal{E}_t \sum_{s=t}^{\infty} \beta^{s-t}(G_s^{F\prime}\mathcal{Q}^F G_s^F) \tag{16}$$

subject to constraint (11).

The leader solves

$$\min_{u_t^L} \frac{1}{2}\mathcal{E}_t \sum_{s=t}^{\infty} \beta^{s-t}(G_s^{L\prime}\mathcal{Q}^L G_s^L) \tag{17}$$

subject to constraint (11) and to the system of first order conditions of the follower's optimization problem.Policy determined by $[F_1^{L\prime}, F_2^{F\prime}]'$ *is discretionary if both policy makers find it optimal to follow* $[F_1^{L\prime}, F_2^{F\prime}]'$ *each time* $s > t$ *given Assumptions (1)-(4).*

We prove in Appendix B the following proposition.

Proposition 1 (First order conditions) *A solution to both commitment and discretionary leadership problem can be written in the following dynamic form:*

$$\mathsf{z}_{t+1} = \mathsf{M}\mathsf{z}_t, \tag{18}$$

$$\mathsf{v}_t = -\mathsf{N}\mathsf{z}_t, \tag{19}$$

where variable $\mathsf{z}_t \equiv \mathsf{y}_t$ *under discretion and* $\mathsf{z}_t \equiv [\mathsf{y}_t', \lambda_t']'$ *under commitment and* λ_t *are predetermined Lagrange multipliers; variable* $\mathsf{v}_t = [\mathsf{x}_t', \mathsf{u}_t^{L\prime}, \mathsf{u}_t^{F\prime}]'$*. Matrices* M *and* N *are functions of policy objectives* $\mathcal{Q}^L$ *and* $\mathcal{Q}^F$ *and of the system matrices A and B.*

4 Estimation Strategy and Empirical Implementation

4.1 Empirical Specification

Using DYNARE toolkit (Juillard (2005)) we estimate the model using Bayesian techniques that have been developed to estimate and evaluate DSGE models (see e.g. An and Schorfheide (2007)).

The empirical specification of the system for estimation consists of equations (18)-(19). In case of *discretion* y_t and v_t only collect endogenous economic variables $\pi_{Ht}, y_t, b_t, i_t, g_t$, exogenous shock variables $(a_t, y_t^*, \varepsilon_t^\pi)$, and two policy shocks $(\varepsilon_t^r, \varepsilon_t^g)$. Shocks (a_t, y_t^*) are assumed to follow an independent first-order autoregressive stochastic processes, and shocks $(\varepsilon_t^\pi, \varepsilon_t^r, \varepsilon_t^g)$ are assumed to be i.i.d.-independent processes. We shall treat the short-term debt as an unobservable variable.

In case of *commitment* y_t collects both endogenous economic variables and unobservable Lagrange multipliers. We use the post-1997 data sample, with initial data coming from the period just after the Bank of England gained independence. If precommitment was possible, then this is the most relevant time point. Hence, we assume that predetermined Lagrange multipliers are all zero at the beginning of estimation period when we initialize the Kalman filter. Using a pre-sample to initialize the Lagrange multipliers would imply the implicit assumption that precommitment happened earlier. In our view it is less plausible assumption. Also, although Ilbas (2011) and Adolfson et al. (2009) use the presample to initialise the Lagrange multipliers, Adolfson et al. (2009) demonstrates that the difference between the two regimes is small in empirical analysis. Woodford (2003a) shows that it is extremely small in a theoretical analysis of difference between the two regimes.

4.2 Priors

We assume that the prior distributions are independent, we also implement size restrictions on the parameters, such as non-negativity, by choosing appropriate prior distributions and re-scaling parameters where needed.

We keep a number of parameters fixed, as some of them are related to steady state variables and could not be estimated from a log-linearised model. We calibrate the discount factor, β, to be 0.99, which implies an annual steady state interest rate of about 4%. The steady state tax rate is set to 0.36, as the data suggest, and the steady state debt to annual GDP ratio is set to zero.[9]

In our model only σ_α is a structural parameter, which depends on η, α, σ. We chose to calibrate α and η and estimate σ, and thus obtain σ_α. This has the advantage that we are able to compare our estimates of σ with those available in the literature. We calibrate $\eta = 1$ following Lubik and Schorfheide (2007) and calibrate $\alpha = 0.3$ using the data on import share.

As our model is stylised and simple, potential misspecification will be reflected in tensions

[9] We work with one-period debt stock, its proportion in the total debt stock is relatively small over the observed period, and the average value over the observed period should not necessarily coincide with steady state values. We also checked alternative calibrations but did not see important differences.

between priors and posteriors for structural parameters θ, σ and φ. We set the mean of the Calvo parameter θ close to 0.75 which assumes the average length of fixed price contracts is around one year. Similar to Smets and Wouters (2003) we choose the prior distribution of φ with mean 2.We assumed that σ is distributed between 1 and 50 and chose prior with mean 10. This falls in between the estimates in Smets and Wouters (2003), who choose prior distribution with mean 1.0 and with standard error of 0.3 and obtain posterior mean of 1.3, and in Givens (2011), who uses ML estimation in an unconstrained domain and obtains the mean estimate around $\sigma \simeq 500$. We have slightly wider domain than in Smets and Wouters (2003), but we did not allow the estimate of σ to become very big.

We choose priors on the coefficients of the policy objectives, Φ, which are generally consistent with those used in Dennis (2006), Ilbas (2011), and Givens (2011). In order to estimate some policy weights we had to use distributions with compact support, in order to exclude negative values and unrealistically high values of weights to save on the computation time. In these cases we work with wide beta distribution $\mathfrak{B}(0.5, 0.15)$ re-scaled to the appropriate compact support.

Note that the policy weight on interest rate smoothing target $\Phi_{\Delta I}$ can be interpreted as importance of this target relative to the inflation stabilization target. It is widely accepted that the monetary authorities find inflation target as most important, and it would be difficult to justify the mean posterior $\Phi_{\Delta I}$ greater than one if we interpret this coefficient as the relative importance. However, $\Phi_{\Delta I}$ affects the instrument inertia in the implied policy reaction function. The empirical reaction function may not be fully determined by either commitment or discretion, it may have some non-strategic components which we cannot identify within this framework. The presence of such non-strategic components may imply a large estimate of $\Phi_{\Delta I}$. Following Dennis (2006) and Ilbas (2011) we do not constrain $\Phi_{\Delta I}$ to be less than one.[10] We discuss robustness of our findings to the choice of prior distributions.

The first three columns of Tables 1 and 2 give an overview of our assumptions regarding the prior distribution of parameters. All the variances of the shocks are assumed to be distributed as an inverted Gamma distribution with a degree of freedom equal to 2. This distribution guarantees a positive variance within a rather wide domain. The means are taken from similar studies, predominantly from Dennis (2006), Ilbas (2011), Givens (2011) and Fragetta and Kirsanova (2010). In the final version of our results we keep fixed $\Phi_{MYG} = \Phi_{FYG} = \Phi_{yg}$. Relaxing this assumption leads to an increase in computational time without change in results, as the marginal

[10] There is no wide agreement that the policy weight on instrument smoothing in fiscal objectives should not dominate the inflation target.

data density is flat in these parameters.

Note that more diffuse priors do not necessarily deliver higher marginal data density. While the in-sample fit improves slightly, wider priors relax some of the parameter restrictions and this leads to a larger penalty for model complexity. The second effect can outweigh the first one and this leads to an overall fall in the marginal data density.

4.3 Data

In our empirical analysis we use the same data set as in Fragetta and Kirsanova (2010), that includes observations on real GDP, the GDP deflator, the nominal interest rate and the government spending-to-GDP ratio for the UK. All the data are seasonally adjusted and measured at quarterly frequencies. We take the post-1997 period 1998:1-2008:2. This choice is made to ensure stability of monetary and fiscal policy objectives. All of the UK data series are obtained from the Office of National Statistics Database.[11] Home inflation rates are defined as log differences and multiplied by 100 to obtain quarterly percentage rates. We use interest rates on three month Treasury bills which closely follows the rate that is targeted by the Bank of England. As a proxy for government expenditures we take 'current government spending on goods and services'. We therefore do not include interest payments and compensation of government employees. Stochastic trend is removed from the data series on real GDP. All data series are demeaned prior to estimation.

5 Empirical Results

In Tables 1 and 2 we report the prior and Bayesian estimated posterior distributions in both policy regimes. We plot the posterior distributions obtained through the Metropolis-Hastings simulations in Figure 1.[12] The results in Tables 1 and 2 and the prior and posterior distributions in Figure 1 are based on joint estimation of policy weights and structural coefficients. Each subplot reports a prior distribution of a parameter (solid line) and a posterior distribution of the parameter (bars).

Table 1: Optimal Monetary and Fiscal Policy under Commitment

		Prior Distribution			Estimated Maximum Posterior		Posterior Distribution		
		type	mean	s.d.	mode	s.d.	5%	50%	95%
Structural Parameters									
productivity	ρ_a	beta	0.5	0.15	0.683	0.204	0.470	0.715	0.947
world demand	ρ_{y^*}	beta	0.5	0.15	0.666	0.147	0.433	0.619	0.820
Calvo param.	θ	beta	0.75	0.015	0.748	0.014	0.724	0.747	0.772
labour utility	φ	norm	2.5	0.25	2.633	0.241	2.316	2.622	3.025
cons. utility	σ	norm	10.0	2.5	10.97	2.38	7.478	10.76	14.75
Theoretical weights, given estimated parameters θ, φ and σ									
output stab.	Φ_y						0.0248	0.0268	0.0285
spend. stab.	Φ_g						0.0050	0.0054	0.0058
Monetary Objectives									
output stab.	Φ_{MY}	gam	0.25	0.15	0.079	0.066	0.023	0.118	0.215
spend. stab.	Φ_{MG}	gam	0.25	0.15	0.160	0.120	0.034	0.233	0.433
inter. smooth.	$\Phi_{\Delta I}$	gam	2.00	1.00	5.914	1.38	3.684	5.604	7.630
Fiscal Objectives									
output stab.	Φ_{FY}	gam	0.25	0.15	0.083	0.049	0.031	0.101	0.169
spend. stab.	Φ_{FG}	gam	0.25	0.15	0.016	0.013	0.002	0.026	0.049
spend. smooth.	$\Phi_{\Delta G}$	gam	2.00	1.00	4.136	1.638	1.769	3.973	5.952
debt target	Φ_{FB}	beta	0.0006	0.0002	0.0006	0.0002	0.0002	0.0005	0.0008
Standard Deviation of Shocks									
productivity	η_a	invg	0.25	2	0.667	0.095	0.419	0.619	0.822
world output	η_{y^*}	invg	0.25	2	0.277	0.069	0.176	0.314	0.412
cost-push	η_π	invg	0.05	2	0.023	0.010	0.015	0.059	0.124
mon. policy	η_r	invg	0.10	2	0.078	0.009	0.066	0.084	0.099
fiscal policy	η_g	invg	0.50	2	1.452	0.160	1.235	1.523	1.803
Log Data Density					-127.681			-127.188	

Table 2: Optimal Monetary and Fiscal Policy under Discretion

		Prior Distribution			Estimated Maximum Posterior		Posterior Distribution		
		type	mean	s.d.	mode	s.d.	5%	50%	95%
Structural Parameters									
productivity	ρ_a	beta	0.5	0.15	0.551	0.094	0.411	0.568	0.715
world demand	ρ_{y^*}	beta	0.5	0.15	0.880	0.019	0.840	0.870	0.907
Calvo param.	θ	beta	0.75	0.015	0.761	0.014	0.734	0.759	0.782
labour utility	φ	norm	2.5	0.25	2.335	0.242	1.956	2.330	2.699
cons. utility	σ	norm	10.0	2.5	10.65	2.263	6.475	10.23	13.84
Theoretical weights, given estimated parameters θ, φ and σ									
output stab.	Φ_y						0.0227	0.0247	0.0265
spend. stab.	Φ_g						0.0046	0.0050	0.0054
Monetary Objectives									
output stab.	Φ_{MY}	gam	0.25	0.15	0.086	0.022	0.052	0.094	0.129
spend. stab.	Φ_{MG}	gam	0.25	0.15	0.134	0.085	0.026	0.167	0.332
inter. smooth.	$\Phi_{\Delta I}$	gam	2.00	1.00	4.564	1.100	3.008	4.926	6.595
Fiscal Objectives									
output stab.	Φ_{FY}	gam	0.25	0.15	0.234	0.147	0.036	0.267	0.486
spend. stab.	Φ_{FG}	gam	0.25	0.15	0.026	0.019	0.007	0.048	0.089
spend. smooth.	$\Phi_{\Delta G}$	gam	2.00	1.00	3.352	1.141	2.197	4.506	6.761
debt target	Φ_{FB}	beta	0.0006	0.0002	0.0004	0.0002	0.0002	0.0005	0.0008
Standard Deviation of Shocks									
productivity	η_a	invg	0.25	2	0.462	0.078	0.342	0.475	0.595
world output	η_{y^*}	invg	0.25	2	0.282	0.073	0.186	0.331	0.493
cost-push	η_π	invg	0.05	2	0.023	0.009	0.013	0.037	0.074
mon. policy	η_r	invg	0.10	2	0.092	0.011	0.077	0.096	0.115
fiscal policy	η_g	invg	0.5	2	1.439	0.165	1.215	1.522	1.798
Log Data Density					-123.47			-122.87	

5.1 Structural Parameters and Shocks

Overall, the estimates of the structural parameters fall within plausible ranges and are similar for both regimes. The marginal data density is relatively flat in these parameters. For every model the estimate of φ is around $1.0 - 3.0$ implying a rather intermediate estimate of the elasticity of labour supply.

There is very little difference in the estimate of the elasticity of intertemporal substitution, $1/\sigma$, between the two cases. It is apparent that the value function is relatively flat in σ : the mean and standard error of the posterior distribution is only slightly different from their priors. We shall discuss in section 5.3 the role of σ in the identification of policy regime.

The data do not conflict with the prior distribution of the Calvo parameter, θ. The estimates suggest that prices are kept the same for about one year. This is a reasonable result and does not contradict most of the evidence.

We find that the productivity and the world demand shocks exhibit persistence, but the extent of persistence is different for commitment and discretion. Productivity shock is found more persistent under commitment, and the world demand shock is more persistent under discretion. The estimates of standard deviations for all structural shocks are very close to those obtained in Smets and Wouters (2003), and in Lubik and Schorfheide (2007), for equally stylized models.

5.2 Policy Preference Parameters

As we argued above, we estimate policy weights as independent parameters, without imposing cross-restrictions between them and structural parameters of the model, θ, φ and σ. For comparison, however, we report policy weights of a benevolent policy maker, given the estimated θ, φ and σ. Tables 1 and 2 report the distributions obtained by the Monte Carlo simulations. The Tables demonstrate that in most cases the unconstrained estimates of policy weights $\Phi_{MY}, \Phi_{MG}, \Phi_{FY}, \Phi_{FG}$ are significantly bigger than the corresponding theoretical weights Φ_y and Φ_g.

The results in Figure 1 show that for each regime the posterior distribution of the weight on the output stabilization target Φ_{MY} in the *monetary policy objectives* is more concentrated and with a smaller mean than the prior. The posterior distribution of Φ_{MG} is more concentrated than

[11] The ONS codes for the data series are GZSN, YBHA, AJRP, YBGB.

[12] The posterior distribution of each parameter that was obtained through simulations using the Metropolis-Hastings algorithm. This is a Markov chain algorithm, which draws from the exact posterior density and our results here are based on 50000 draws. A sample of 50000 draws was sufficient to ensure convergence of the MH sampling algorithm. The acceptation rate was around 40%.

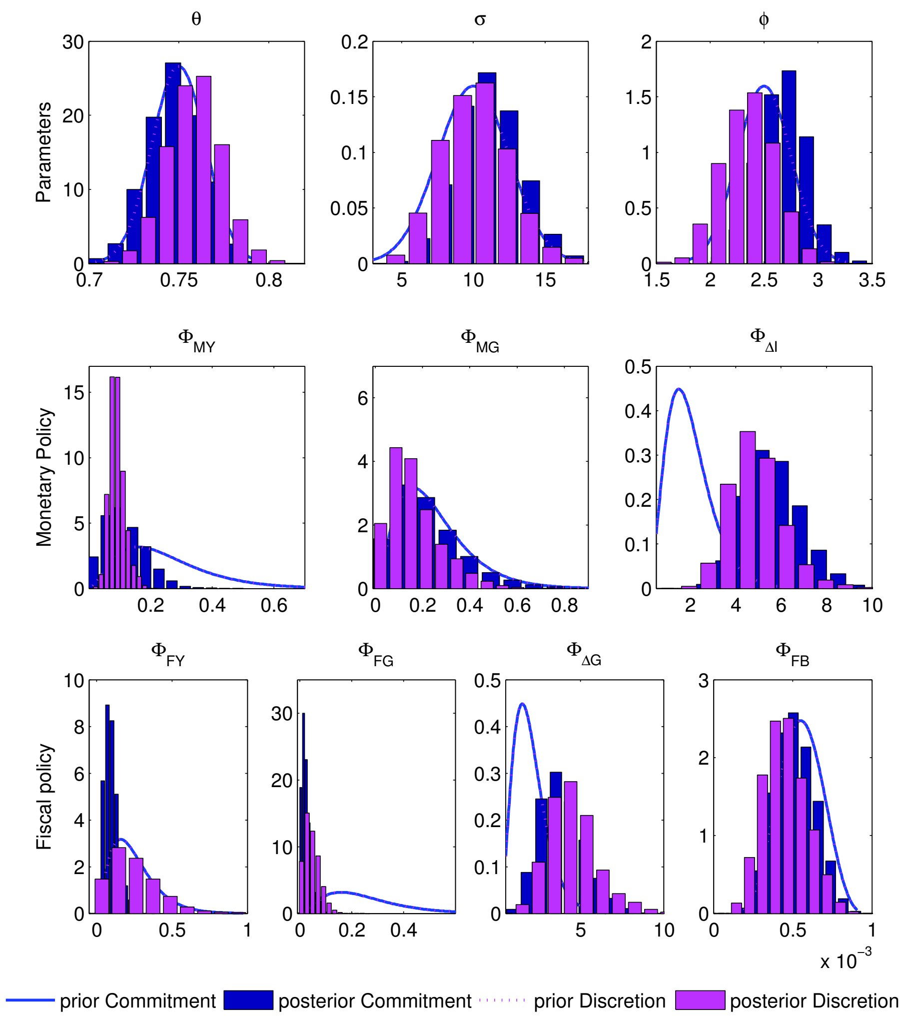

Figure 1: Prior and posterior distributions of the policy preference parameters of optimal monetary and fiscal policy under commitment and discretion.

the prior distribution, but only under discretion.

We estimate a substantial weight on the interest rate smoothing target, $\Phi_{\Delta I}$. Moreover, the corresponding plots demonstrate that the posterior distribution has shifted to the right from the prior for both discretion and commitment. As we discuss above, an interest rate smoothing target can be a consequence of some other constraints on monetary policy, which are not accounted for in this model. The largest weight is estimated for the case under commitment. In other words, in order to approximate the economic data the policy maker who can commit should have objectives that are far more distorted than the benevolent objectives. In contrast, the policy maker who acts under discretion should have less distorted objectives. This estimate plays an important role in identifying policy regime, as we discuss in the next section.

The estimation of the *fiscal policy objectives* suggests that the fiscal authorities have a statistically significant output stabilization target under commitment, with relative weight Φ_{FY}. Under discretion, however, the posterior distribution of Φ_{FY} is not very much different from the prior so the value function is flat in this parameter. We also find that the weight on spending stabilization in fiscal objectives, Φ_{FG}, is small in value for both regimes.

We find no evidence of that the fiscal authorities have strong incentives to stabilize debt: the weight on the debt target, Φ_{FB}, is estimated to be very small for both policy regimes. Although the posterior distribution is not more concentrated than the prior of Φ_{FB}, the posterior mean is different. Moreover, the marginal data density rises sharply when the compact beta-distributed support of the prior distribution of Φ_{FB} is rescaled to be closer to zero.

Similar to the results for monetary objectives, we estimate large weight on the instrument smoothing target of fiscal authorities, $\Phi_{\Delta G}$.

Overall, as anticipated, commitment and discretion models yield different estimates of policy objectives. The main difference is in the importance of output stabilization target. Under discretion it is a clearly identified target of monetary authorities, while under commitment it is a target of fiscal authorities. In both regimes, however, we do not find that policy preferences of the fiscal authority with respect to inflation and output stabilization conflict with those preferences of the monetary authority. The estimates of these coefficients are with smaller or bigger variance, but the mean estimates are similar. Of course, the monetary and fiscal policy authorities face different constraints and, as a result, have additional terms in policy objectives.

5.3 Model Comparison

The marginal data density for the model under discretionary policy is higher, than it is for the model under commitment policy. Thus, the monetary and fiscal policy regime in the UK, under the assumption of fiscal leadership, can best be described by a discretionary policy regime. The posterior odds is 0.015, which means that the probability that the actual data were generated by the model with optimal commitment policy, rather than by the model with optimal discretionary policy, is around 1.5%.

We obtain relatively strong dominance of the discretionary policy regime. This result is robust to the wide range of priors for all coefficients. In particular, the marginal data density is most sensitive to our choice of prior distributions for structural parameter σ and for policy parameter $\Phi_{\Delta I}$. More specifically, if we interpret parameter $\Phi_{\Delta I}$ as the relative importance of instrument stabilization target only, and if we restrict $\Phi_{\Delta I}$ to be between zero and one, then we get even stronger dominance of the discretionary model, but we do not get noticeable effects on the estimates of other parameters. However, the marginal data densities of both models fall sharply.

Similarly, if we impose much wider prior for σ, as discussed in section 4.2, then we get stronger dominance of the model under discretionary policy. The marginal data density increases in σ for both models.

Note that both parameters, σ and $\Phi_{\Delta I}$ are jointly estimated to match volatilities of (difference in) consumption and of the real interest rate in Euler equation (2). Bigger σ helps to match relatively smooth consumption data, while bigger $\Phi_{\Delta I}$ generates smoother fitted values of interest rate and so also improves the fit of the Euler equation. But the effects of σ and $\Phi_{\Delta I}$ are not substitutes, and the marginal data density rises with both higher σ and higher $\Phi_{\Delta I}$ in a very wide domain. We can get a *weak* dominance of commitment only if we substantially restrict the support for σ. However, even if we impose $\sigma = 1$ and allow for very high $\Phi_{\Delta I}$, the dominance will be weak, with posterior odds of about 0.1. Because with lower σ the marginal data density of both models will fall sharply we disregard this case.

Further, Figure 2 reports the historic and the one-step ahead predicted data under the two policy regimes. It is apparent that commitment yields better in-sample fit for the interest rate reaction than does discretion, but it yields worse fit for both (growth rate of) output and inflation.

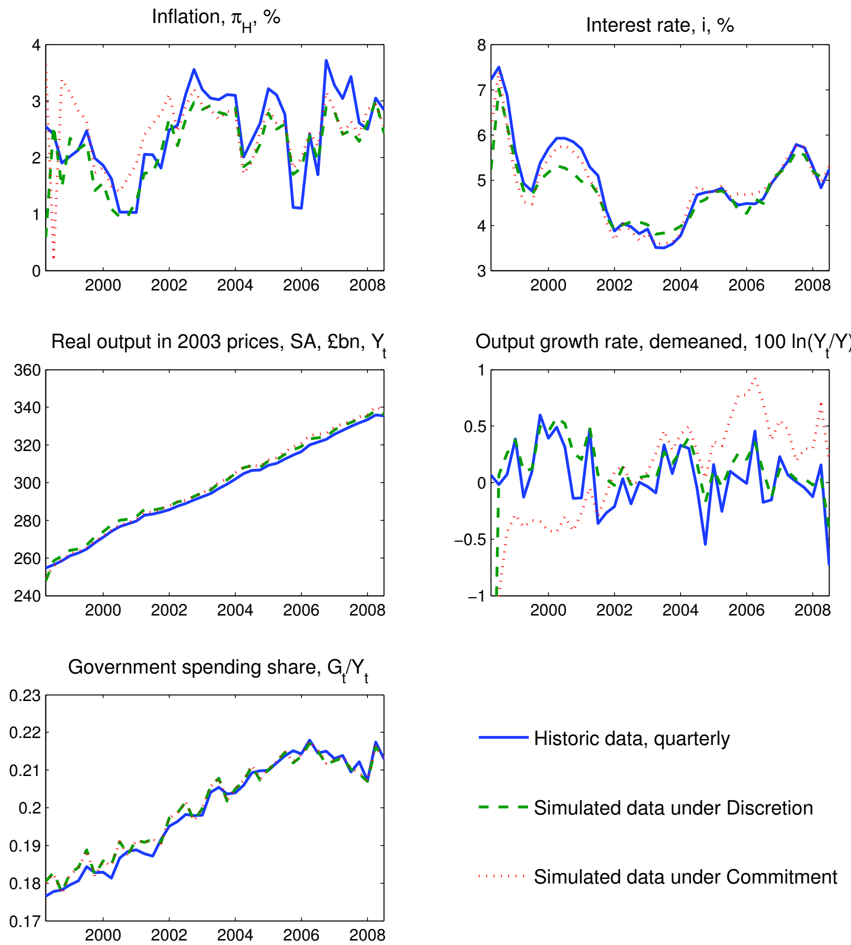

Figure 2: In-sample fit. Historic and one-step ahead predicted data under different policy regimes.

5.4 Implied Policy Rules

Proposition 1 states that policy reactions can be written as linear functions of predetermined state variables. The implied discretionary policy reaction functions can be written as

$$\begin{aligned} i_t &= \underset{(0.0496)}{0.1681^*}\eta_{\pi,t} - \underset{(0.0225)}{0.0890^*}\eta_{a,t} - \underset{(0.0740)}{0.2471^*}\eta_{y^*,t} + \underset{(0.0313)}{0.5295^*}i_{t-1} + \underset{(0.0045)}{0.0185^*}g_{t-1} + \underset{(0.0008)}{0.0031^*}b_{t-1} \\ g_t &= \underset{(0.0112)}{-0.0037}\eta_{\pi,t} - \underset{(0.0072)}{0.0013}\eta_{a,t} + \underset{(0.0916)}{0.0719}\eta_{y^*,t} + \underset{(0.0343)}{0.0218}i_{t-1} + \underset{(0.0224)}{0.8971^*}g_{t-1} - \underset{(0.0049)}{0.0144^*}b_{t-1} \end{aligned}$$

where we substitute means of feedback coefficients and report standard errors in parentheses. The asterisk denotes statistical significance at 95% confidence level.[13]

The set of predetermined state variables in the case of commitment includes Lagrange multipliers. We truncate the system to include feedbacks on economic variables only.[14]

$$\begin{aligned} i_t &= \underset{(0.0157)}{0.0423^*}\eta_{\pi,t} - \underset{(0.0084)}{0.0208^*}\eta_{a,t} - \underset{(0.0393)}{0.0948^*}\eta_{y^*,t} + \underset{(0.0273)}{0.8130^*}i_{t-1} + \underset{(0.0020)}{0.0082^*}g_{t-1} - \underset{(0.0002)}{0.0007^*}b_{t-1} \\ g_t &= \underset{(0.0014)}{-0.0008}\eta_{\pi,t} - \underset{(0.0030)}{0.0029}\eta_{a,t} + \underset{(0.0155)}{0.0176}\eta_{y^*,t} + \underset{(0.0040)}{0.0044}i_{t-1} + \underset{(0.0132)}{0.9161^*}g_{t-1} - \underset{(0.0031)}{0.0107^*}b_{t-1} \end{aligned}$$

For both regimes all coefficients in the monetary policy reactions are statistically significant, while only the persistence coefficient and the feedback on debt coefficient are statistically significant in the fiscal policy reaction functions. It is not surprising that fiscal policy maker is not able to react to contemporary shocks, and so we find these feedback coefficients statistically not different from zeros. The fiscal policy maker feeds back on debt with a coefficient, which is big enough to ensure debt stabilization but small enough to prevent fast convergence of debt back to the base level (steady state) and a loss in welfare.[15]

In both policy regimes the monetary feedback on fiscal instrument is statistically significant. This can be used as an indirect test of the leadership regime. The monetary policy maker, being a follower, has to react to changes in fiscal instrument, whether the fiscal policy maker acts strategically or not (in the latter case the fiscal instrument is just another observed state).[16]

The sign of monetary feedback on debt is negative in the commitment reaction function, and it is positive in the discretion reaction function. The positive coefficient coexists with stronger

[13] In order to compute all moments we use Monte Carlo simulations.

[14] The predetermined Lagrange multipliers are integrals of states and they are (relatively) slow moving variables that set to zero in the period of initial precommitment.

[15] See Kirsanova and Wren-Lewis (2011) who discuss optimality of such policy.

[16] Theoretically, the monetary policy maker should react to *contemporary* changes in fiscal instrument (see equation (23) in Appendix). The presented policy rule is the reduced form of the corresponding structural reaction. However, because of high correlation between current and lagged spending, the statistical significance of contemporary spending in the structural form monetary policy reaction function is likely.

feedback on debt by fiscal authorities, so under discretion the optimal monetary policy prevents too fast debt stabilization by fiscal means.

Our results are generally consistent with those in Ilbas (2011) and in Givens (2011). The estimated weight on instrument smoothing generates optimal coefficients on past instruments that are slightly lower than those reported in these papers.

5.5 Impulse Responses and Counterfactual Simulations

The model dynamics can be further studied by computing impulse response functions. When the fiscal policy maker responds to shocks it knows and exploits the monetary policy reaction function. Impulse responses illustrate these interactions. We report them in Figure 3. Each subplot shows mean responses of observable variables together with 5th and 95th percentiles. We plot impulse responses to each shock in a separate row of subplots. The results for commitment and discretion models are plotted together.

A positive productivity shock reduces the marginal cost. This leads to lower inflation and monetary policy lowers interest rate. A reduction in the real interest rate raises output. Fiscal policy cuts government spending. Debt is reduced because of lower spending, higher output and lower interest rate. Under commitment monetary policy reacts to the productivity shock less aggressively, and fiscal policy is also less able to exploit the monetary policy reaction function. At the same time under commitment the productivity shock is estimated to be more persistent and with higher variance. As a result, the fiscal instrument moves more under commitment than under discretion. This ensures similar variability of inflation under both regimes.

A positive world output shock leads to a large fall in output. Inflation rises because world output shock lowers domestic potential output (under our estimates of σ and subsequent calibration of σ_α) even more so the output gap rises. This fall in output would generate large increase in government debt but the fiscal policy maker reduces the government spending in several first periods and then raises it above the base line. Because a rise in interest rate would also lead to fast debt accumulation, monetary policy does not raise interest rate, accommodates inflation and helps output to recover. The gap is eventually reduced and inflation is reduced too. Under discretion the world output shock is more persistent, but with similar variance. A similar move of the fiscal instrument under discretion and commitment results in long adjustment in interest rate and inflation under discretionary policy.

A cost push shock raises inflation. The fiscal policy maker raises spending and this is followed by an increase in nominal and real interest rates. Output falls and inflation is stabilized. Higher

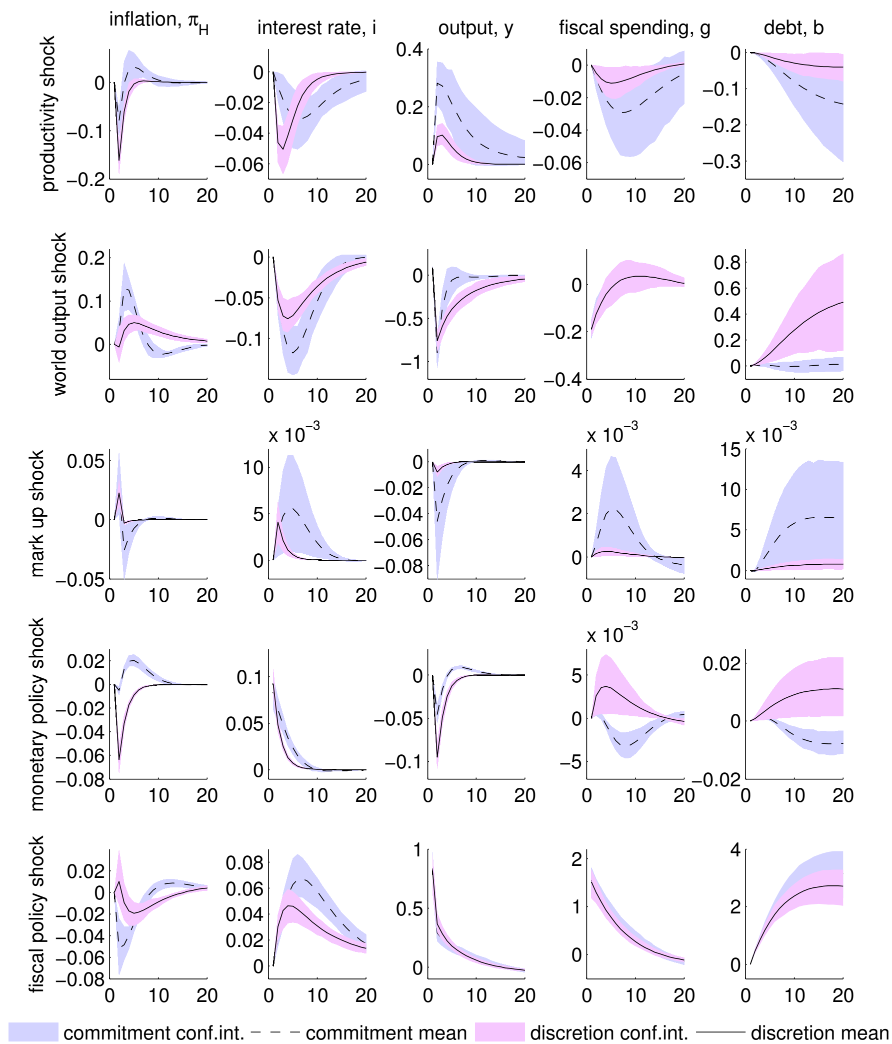

Figure 3: Bayesian impulse response functions to the five shocks for the post-ERM period.

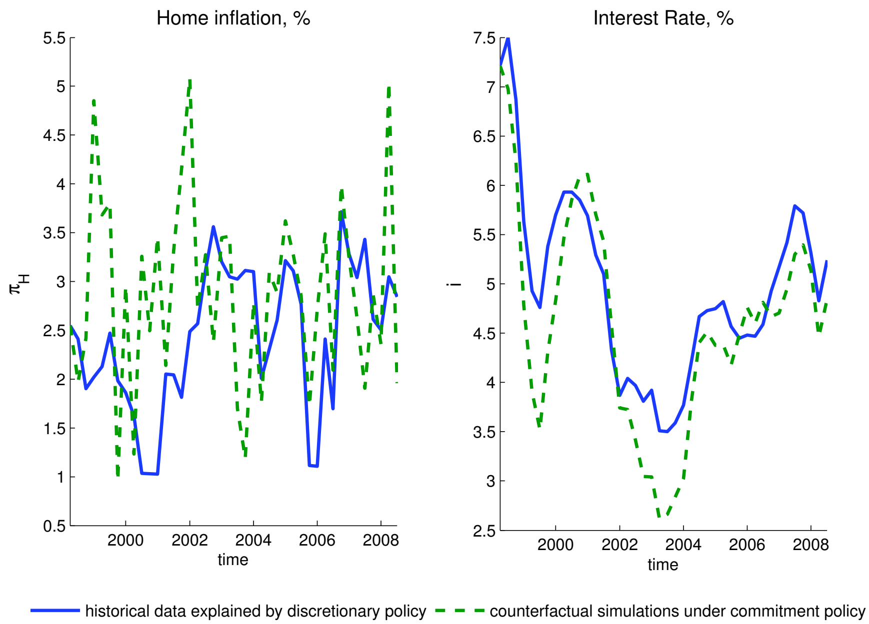

Figure 4: Counterfactual simulations.

interest rate and lower output result in higher debt. In order to achieve the same rise in interest rate, discretionary fiscal policy needs less expansion and output falls by less than under commitment. Interest rate is kept high longer under commitment. This policy results in relatively large output fall and in inflation overshooting. However, the difference is not statistically significant and all reactions are relatively small.

A positive shock to interest rate lowers output and raises debt. Fiscal policy reacts to fall in output and spending initially rises. Because of lower output inflations falls. Monetary policy lowers interest rate sluggishly, but it remains relatively high for a long time. Lower interest rate causes output to increase, and under commitment inflation grows much more than under discretion, but its volatility is smaller. Fiscal policy adjusts by a small amount.

A positive fiscal shock drives output up. There is a small impact on inflation as the effect of a higher output gap on marginal costs is partly offset by the effect of higher spending. The monetary policy maker raises interest rate so output is reduced and inflation is stabilized.

Finally, we conduct a counterfactual experiment. We identify model parameters, policy objectives and shocks under discretion and then investigate what would have happened if the policy was implemented under credible commitment. Figure 4 plots the historical data as simulated under discretionary policy and counterfactual simulations of the data under commitment policy with the same objectives as under discretion. We also show two intermediate cases to explain the outcome.

The interest rate path would have been different under commitment. Most notably the monetary policy was tighter under discretion than it would have been under commitment in 1999-2001 and 2003-2004. Under commitment inflation would be higher than observed in 1999-2002, but then inflation would come back close to the historical data. Using the monetary policy objective as a measure of loss we compute the permanent increase in inflation from target that in terms of central bank loss is equivalent to moving from commitment to discretion. Following e.g. Dennis (2006), Givens (2011) we compute the inflation equivalent as $\pi^{eq} = \sqrt{L_d - L_c}$ where L_d and L_c are losses under discretion and commitment correspondingly. This inflation equivalent is about 0.35%. If the increased volatility of interest rate is not taken into account then the inflation equivalent is 0.54%.

6 Conclusions

This paper identifies the degree of precommitment in monetary and fiscal policy interactions in the UK. We specify a small-scale structural general equilibrium model of a small open economy and estimate it using Bayesian methods. Unlike most existing empirical research we explicitly take into account the solvency constraint faced by fiscal authorities, which plays an important role as an identifying restriction. We also assume that the authorities act non-cooperatively, and may have different objectives. We find that probability that the data were generated by a model of commitment interactions as opposed to discretion is 1.5%.

These results demonstrate that, although the policy authorities communicate policy forecasts in the form of paths, and may even chose not to renege on previously announced policy, this is not enough to convince the private sector that they are able to precommit to the initially chosen policy plan.

The implied policy reaction functions have conventional form. We find that monetary policy maker takes into account all available information, as all feedback coefficients are statistically highly significant. We also find that during the period of investigation fiscal policy remained not very active. Its behaviour is characterized by a policy rule with substantial inertia and with slow feed back on debt: the debt stabilization is fast enough to keep the debt under control and slow enough to prevent a reduction in social welfare.

We demonstrate that commitment and discretion models yield different estimates of policy objectives. We identified the presence of output stabilization target for monetary authorities, which is more statistically significant for policy under discretion than under commitment. Under the assumption of commitment, we also find the output stabilization target for fiscal authorities. At the same time we did not find a conflict of monetary and fiscal policy inflation and output stabilisation targets, as the mean estimates of these policy weights were similar. Finding differences in estimates of policy weights for different degrees of precommitment calls for better policy communication. Prior information about at least some policy objectives of both policy makers may help the private sector to identify the policy regime and steer the private sector's expectations in the desired direction.

A Social welfare

Fragetta and Kirsanova (2010) derive the intra-period social loss:

$$L_t = \Phi_y y_t^2 + \Phi_{yg} g_t y_t + \Phi_g g_t^2 + \pi_{Ht}^2$$

where

$$\Phi_y = a_1 + a_2 + a_3, \Phi_{yg} = a_2 + 2a_3, \Phi_g = a_3.$$

and

$$a_0 = \frac{1}{2}\left(\frac{1}{\kappa_2}+\frac{1}{2}\frac{(1-\sigma)}{\kappa_2^2}\right)(\varphi+\frac{1}{\epsilon})\frac{\epsilon^2}{(1-\theta\beta)}\frac{\theta}{1-\theta}, a_1 = -\left(\frac{\kappa_1}{\kappa_2}-\frac{1}{2}\left(\frac{1}{\kappa_2}+\frac{1}{2}\frac{(1-\sigma)}{\kappa_2^2}\right)(1+\varphi)\right)/a_0$$

$$a_2 = -\frac{\kappa_4}{\kappa_2}/a_0, a_3 = -\left(\frac{1}{2}\left(\frac{1}{\kappa_2}+\frac{1}{2}\frac{(1-\sigma)}{\kappa_2^2}\right)\frac{G}{Y}(1-\sigma)-\frac{\kappa_8}{\kappa_2}\right)/a_0, a_4 = \frac{\kappa_5}{\kappa_2}/a_0' a_5 = a_6 = 0, a_7 = \frac{\kappa_6}{\kappa_2}/a_0$$

$$\kappa_1 = \frac{1}{2}\left(1-\frac{\left((1-\alpha)+2\alpha\eta\sigma+\frac{\alpha\eta\sigma^2\left(1-\eta\alpha^2+\eta\alpha\right)}{(1-\alpha)^2}\right)}{\theta\left(\frac{\sigma}{(1-\alpha)\sigma_\alpha}\right)^2}\right), \kappa_2 = \frac{\sigma\theta}{(1-\alpha)\,\sigma_\alpha}, \kappa_3 = -\frac{\alpha\omega\theta}{(1-\alpha)}$$

$$\kappa_4 = -\frac{(1-\theta)}{\theta}\frac{(\alpha-1)^3+\alpha\sigma\eta\left(4\alpha-\sigma-2\alpha^2+\alpha^2\sigma\eta-\alpha\sigma\eta-2\right)}{\left(2\alpha-\alpha^2+\alpha^2\sigma\eta-2\alpha\sigma\eta-1\right)^2}, \kappa_8 = \frac{(1-\theta)}{2}(1+\kappa_4),$$

$$\kappa_5 = \left(\frac{\left(\alpha-\sigma-\eta\alpha\sigma-\alpha^2+\eta\alpha^2\sigma\right)\eta\alpha\sigma_\alpha}{(1-\alpha)}+\frac{\left((1-\alpha)+2\alpha\eta\sigma+\frac{\alpha\eta\sigma^2\left(1-\eta\alpha^2+\eta\alpha\right)}{(1-\alpha)^2}\right)\alpha\omega(1-\alpha)\sigma_\alpha^2}{\sigma^2}\right),$$

$$\kappa_6 = -\kappa_5(1-\theta), \kappa_7 = -\frac{1}{2}\frac{\alpha\theta\left((\alpha-1)^3+\eta\sigma\left(3\alpha\sigma\eta-3\alpha^2\sigma\eta+\alpha^3\sigma\eta-\sigma-2(\alpha-1)^3\right)\right)}{\left(2\alpha-\alpha^2-1-2\alpha\sigma\eta+\alpha^2\sigma\eta\right)^2}.$$

B Proof of Proposition 1

Proof. We first solve the problem under commitment. Minimization problem of the Follower can be presented by the following intra-period Lagrangian:

$$\begin{aligned}H_s^F = &\frac{1}{2}\beta^{s-t}(\mathsf{x}_s' Q_{22}^F \mathsf{x}_s + 2\mathsf{y}_s' Q_{12}^F \mathsf{x}_s + \mathsf{y}_s' Q_{11}^F \mathsf{y}_s + 2\mathsf{u}_s^L P_{11}^{F\prime}\mathsf{y}_s + 2\mathsf{u}_s^L P_{21}^{F\prime}\mathsf{x}_s + 2\mathsf{u}^F P_{12}^{F\prime}\mathsf{y}_s + 2\mathsf{u}_s^F P_{22}^{F\prime}\mathsf{x}_s\\ &+ \mathsf{u}_s^L R_{11}^F U_s^L + 2\mathsf{u}_s^L R_{12}^F \mathsf{u}_s^F + \mathsf{u}_s^F R_{22}^F \upsilon_s^F + \lambda_{s+1}^{Fy\prime}(A_{11}\mathsf{y}_s + A_{12}\mathsf{x}_s + D_1\mathsf{u}_s^L + B_1\mathsf{u}_s^F - \mathsf{y}_{s+1})\\ &+ \lambda_{s+1}^{Fx\prime}(A_{21}\mathsf{y}_s + A_{22}\mathsf{x}_s + D_2\mathsf{u}_s^L + B_2\mathsf{u}_s^F - \mathsf{x}_{s+1}))\end{aligned}$$

where Lagrange multipliers λ^{Fy} are non-predetermined (as those on predetermined variables) with terminal conditions and λ^{Fx} are predetermined with initial conditions. The first order conditions are:

$$0 = Q_{22}^F\mathsf{x}_s + Q_{21}^F\mathsf{y}_s + P_{21}^F\mathsf{u}_s^L + P_{22}^F\mathsf{u}_s^F + \beta A_{12}'\lambda_{s+1}^{Fy} + \beta A_{22}'\lambda_{s+1}^{Fx} - \lambda_s^{Fx}$$
$$0 = Q_{12}^F\mathsf{x}_s + Q_{11}^F\mathsf{y}_s + P_{11}^F\mathsf{u}_s^L + P_{12}^F\mathsf{u}_s^F + \beta A_{11}'\lambda_{s+1}^{Fy} + \beta A_{21}'\lambda_{s+1}^{Fx} - \lambda_s^{Fy}$$
$$0 = P_{12}^{F\prime}\mathsf{y}_s + P_{22}^{F\prime}\mathsf{x}_s + R_{12}^{F\prime}\mathsf{u}_s^L + R_{22}^F\mathsf{u}_s^F + \beta B_1'\lambda_{s+1}^{Fy} + \beta B_2'\lambda_{s+1}^{Fx}$$

The minimization problem of the Leader or Fiscal Policy maker

$$
\begin{aligned}
H_s^L = {} & \frac{1}{2}\beta^{s-t}(\mathsf{x}_s' Q_{22}^L \mathsf{x}_s + 2Y_s' Q_{12}^L \mathsf{x}_s + \mathsf{y}_s' Q_{11}^L \mathsf{y}_s + 2\mathsf{u}^L P_{11}^{L\prime} \mathsf{y}_s + 2\mathsf{u}^L P_{21}^{L\prime} \mathsf{x}_s + 2\mathsf{u}^F P_{12}^{L\prime} \mathsf{y}_s + 2\mathsf{u}_s^F P_{22}^{L\prime} \mathsf{x}_s \\
& + \mathsf{u}_s^L R_{11}^L \mathsf{u}_s^L + 2\mathsf{u}_s^L R_{12}^L \mathsf{u}_s^F + \mathsf{u}_s^F R_{22}^L \mathsf{u}_s^F + \lambda_{s+1}^{Ly\prime}(A_{11}\mathsf{y}_s + A_{12}\mathsf{x}_s + D_1 \mathsf{u}_s^L + B_1 \mathsf{u}_s^F - \mathsf{y}_{s+1}) \\
& + \lambda_{s+1}^{Lx\prime}(A_{21}\mathsf{y}_s + A_{22}\mathsf{x}_s + D_2 \mathsf{u}_s^L + B_2 \mathsf{u}_s^F - \mathsf{x}_{s+1}) + \nu_s^{Ly\prime}\Big(A_{11}'\beta\lambda_{s+1}^{Fy} + A_{21}'\beta\lambda_{s+1}^{Fx} - \lambda_s^{Fy} + \mathcal{Q}_{12}^F \mathsf{x}_s \\
& + \mathcal{Q}_{11}^F \mathsf{y}_s + P_{11}^F \mathsf{u}_s^L + P_{12}^F \mathsf{u}_s^F\Big) + \nu_s^{Lx\prime}\Big(\beta A_{12}'\lambda_{s+1}^{Fy} + \beta A_{22}'\lambda_{s+1}^{Fx} - \lambda_s^{Fx} + \mathcal{Q}_{22}^F \mathsf{x}_s + \mathcal{Q}_{21}^F \mathsf{y}_s \\
& + P_{21}^F \mathsf{u}_s^L + P_{22}^F \mathsf{u}_s^F\Big) + \nu_s^{Lu\prime}\Big(P_{12}^{L\prime}\mathsf{y}_s + P_{22}^{L\prime}\mathsf{x}_s + R_{12}^{F\prime}\mathsf{u}_s^L + R_{22}^F \mathsf{u}_s^F + \beta B_1'\lambda_{s+1}^{Fy} + \beta B_2'\lambda_{s+1}^{Fx}\Big))
\end{aligned}
$$

where Lagrange multipliers λ^{Ly} are non-predetermined (as those on predetermined variables) with terminal conditions and λ^{Lx} are predetermined with initial conditions. The first order conditions are:

$$
\begin{aligned}
& 0 = Q_{22}^L \mathsf{x}_s + Q_{21}^L \mathsf{y}_s + P_{21}^L \mathsf{u}_s^L + P_{22}^L \mathsf{u}_s^F + \mathcal{Q}_{12}^{F\prime}\nu_s^{Ly} + \mathcal{Q}_{22}^{F\prime}\nu_s^{Lx} + P_{22}^F \nu_s^{Lu\prime} + \beta A_{12}'\lambda_{s+1}^{Ly} + \beta A_{22}'\lambda_{s+1}^{Lx} - \lambda_s^{Lx}, \\
& 0 = Q_{12}^L \mathsf{x}_s + Q_{11}^L \mathsf{y}_s + P_{11}^L \mathsf{u}_s^L + P_{12}^L \mathsf{u}_s^F + \mathcal{Q}_{11}^{F\prime}\nu_s^{Ly} + \mathcal{Q}_{21}^{F\prime}\nu_s^{Lx} + P_{12}^F \nu_s^{Lu} + \beta A_{11}'\lambda_{s+1}^{Ly} + \beta A_{21}'\lambda_{s+1}^{Lx} - \lambda_s^{Ly}, \\
& 0 = P_{11}^{L\prime}\mathsf{y}_s + P_{21}^{L\prime}\mathsf{x}_s + R_{11}^L \mathsf{u}_s^L + R_{12}^L \mathsf{u}_s^F + P_{11}^{F\prime}\nu_s^{Ly} + P_{21}^{F\prime}\nu_s^{Lx} + R_{12}^F \nu_s^{Lu} + \beta D_1'\lambda_{s+1}^{Ly} + \beta D_2'\lambda_{s+1}^{Lx}, \\
& 0 = P_{12}^{L\prime}\mathsf{y}_s + P_{22}^{L\prime}\mathsf{x}_s + R_{12}^{L\prime}\mathsf{u}_s^L + R_{22}^L \mathsf{u}_s^F + P_{12}^{F\prime}\nu_s^{Ly} + P_{22}^{F\prime}\nu_s^{Lx} + R_{22}^{F\prime}\nu_s^{Lu} + \beta B_1'\lambda_{s+1}^{Ly} + \beta B_2'\lambda_{s+1}^{Lx}, \\
& 0 = A_{11}\nu_s^{Ly} - \nu_{s+1}^{Ly} + A_{12}\nu_s^{Lx} + B_1\nu_s^{Lu}, \qquad 0 = A_{21}\nu_s^{Ly} + A_{22}\nu_s^{Lx} - \nu_{s+1}^{Lx} + B_2\nu_s^{Lu}, \\
& 0 = A_{11}\mathsf{y}_s + A_{12}\mathsf{x}_s + D_1\mathsf{u}_s^L + B_1\mathsf{u}_s^F - \mathsf{y}_{s+1}, \qquad 0 = A_{21}\mathsf{y}_s + A_{22}\mathsf{x}_s + D_2\mathsf{u}_s^L + B_2\mathsf{u}_s^F - \mathsf{x}_{s+1}.
\end{aligned}
$$

The system of first order conditions to both optimization problems can be written as:

$$
G\begin{bmatrix} K_{s+1} \\ L_{s+1} \end{bmatrix} = D\begin{bmatrix} K_s \\ L_s \end{bmatrix}
$$

where $K_s = (\mathsf{y}_s', \mu_s^{x\prime})'$ is predetermined variable, and $L_s = (\mathsf{u}_s', \mathsf{x}_s', \mu_s^{y\prime})'$ is non-predetermined variable and $\mu_s^{y\prime}$ and $\mu_s^{x\prime}$ collect corresponding Lagrange multipliers. Matrix G can be singular, so using singular form decomposition (see Söderlind (1999)) we find the solution of the system in the form:

$$
\begin{bmatrix} Y_{s+1} \\ \mu_{s+1}^x \end{bmatrix} = Z_{11}S_{11}^{-1}T_{11}Z_{11}^{-1}\begin{bmatrix} Y_s \\ \mu_s^x \end{bmatrix}, \begin{bmatrix} \mathsf{u}_s \\ X_s \\ \mu_s^y \end{bmatrix} = Z_{21}Z_{11}^{-1}\begin{bmatrix} Y_s \\ \mu_s^x \end{bmatrix} \tag{20}
$$

where matrices Z, S and T are obtained when solving the generalized eigenvalue problem. Note that S_{11} and Z_{11} have to be invertible, but T_{11} does not need to be. Moreover, if D has any zero roots, then any transformations with Hermitian matrices leave them zero, and they are collected in the top left part of T, such that $T_{ii}/S_{ii} < 1$.

Denote $\mathsf{M} = Z_{11}S_{11}^{-1}T_{11}Z_{11}^{-1}$, $N = -Z_{21}Z_{11}^{-1}$, and matrix N contains first $k_F + k_F + n_2$ rows of matrix N. Then, system (20) is written in form of (18)-(19).

We now prove the proposition for discretion.

Solution to a discretionary problem in any time t gives a value function for each policy maker i, $i \in \{L, F\}$, which is quadratic in the state variables,

$$W_t^i = \frac{1}{2}\mathsf{y}_t' S^i \mathsf{y}_t \tag{21}$$

a linear relation between the forward-looking variables

$$\mathsf{x}_t = -N\mathsf{y}_t \tag{22}$$

and a linear policy reaction function

$$\mathsf{u}_t^F = -F^F\mathsf{y}_t - L\mathsf{u}_t^L, \tag{23}$$

$$\mathsf{u}_t^L = -F^L\mathsf{y}_t, \tag{24}$$

where $L = -\partial\mathsf{u}_t^F/\partial\mathsf{u}_t^L$: in a leadership equilibrium the follower treats the leader's policy instrument parametrically.

We seek solution in the class of matrices with time-invariant coefficients. Given y_0 and system matrices A and B, matrices N, F^F, F^L and L, define the trajectories $\{\mathsf{y}_s, \mathsf{x}_s, \mathsf{u}_s\}_{s=t}^{\infty}$ in a unique way and vice versa: if we know that $\{\mathsf{y}_s, \mathsf{x}_s, \mathsf{u}_s\}_{s=t}^{\infty}$ solve the discretionary optimization problem then, by construction, there are unique time-invariant linear relationships between them which we label by N, F^F, F^L and L. Matrix S^i defines the cost-to-go for a policy maker i along a trajectory. Given the one-to-one mapping between equilibrium trajectories and $\{\mathsf{y}_s, \mathsf{x}_s, \mathsf{u}_s\}_{s=t}^{\infty}$ and the sextuple of matrices $\mathcal{T} = \{N, F^F, F^L, L, S^F, S^L\}$, it is convenient to continue with definition of policy equilibrium in terms of $\mathcal{T}$, not trajectories. This approach has become standard since Oudiz and Sachs (1985) and Backus and Driffill (1986).

The first order conditions on $\mathcal{T}$ are derived in Blake and Kirsanova (2011). We substitute (24) into (23) and obtain equation (19) with $\mathsf{N} = [N', \left(F^F - LF^L\right)', F^{L\prime}]'$. We substitute (22),(24) into (23) into equation 11 and obtain equation (18) with $M = A_{11} - A_{12}N - B_{11}F^L - B_{12}\left(F^F - LF^L\right)$. ■

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