

# Taking Personalities out of Monetary Policy Decision Making? Interactions, Heterogeneity and Committee Decisions in the Bank of England's MPC.\*

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## Abstract

The transparency of the monetary policymaking process at the Bank of England has provided very detailed data on both the votes of individual members of the Monetary Policy Committee and the information on which they are based. In this paper we consider interval censored responses of individual committee members in the context of a model in which inflation forecast targeting is used but there is both heterogeneity and interaction among the members of the committee. We find substantial heterogeneity in the policy reaction function across members. Further, we identify significant interactions between individual decisions of the committee members. The nature of these interdependencies inform about information sharing and strategic interactions within the Bank of England's Monetary Policy Committee.

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Keywords: Monetary policy; Interest rates; Committee decision making; Expectation-Maximisation Algorithm; Spatial Weights Matrix; Spatial Error Model.

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# 1 Introduction

It is widely believed that committee decisions in the context of monetary policy decision making have three major benefits . First, a committee can be used to take personalities out of monetary policy decisions and render the policy decisions more objective. Second, potential heterogeneity across committee members provides an opportunity to consider and debate a wide range of possible policy responses to current and expected future macroeconomic conditions. Third, committee decisions that evolve through deliberation, debate and information sharing would typically exhibit lower variation in the path of future inflation and greater social welfare.

These potential benefits of committee decision making is of particular relevance in the context of monetary policy. Empirical evidence strongly highlights the role of personalities and individual preferences of central bankers in the conduct of monetary policy. There is a substantial literature in the US that uses transcripts of the FOMC to study monetary policymaking. See for example Belden (1989), Havrilesky and Gildea (1991), Edison and Marquez (1998) and Chappell *et al.* (2004). This has provided a number of insights into how committees work and the role played by individual members, especially the Chairman. By implication, the literature therefore acknowledges heterogeneity amongst policy makers within a monetary policy committee.

This body of work has been followed much more recently by studies of the monetary policymaking process of the Bank of England. In 1992, the United Kingdom, following New Zealand and Sweden, adopted inflation targeting. This was augmented by a much more open system of decision-making, but ultimately decisions on interest rates were still made by the Government. In 1997 the Bank of England was given full operational independence. To support this new policy regime, very detailed information about interest rate decisions has been provided. Recent literature has used such detailed information, including votes by individual members of the Monetary Policy Committee, to study several aspects of monetary policymaking at the Bank of England<sup>1</sup>. While the above literature provides some evidence on heterogeneity across members of a monetary policy committee, there is little empirical work on understanding either the sources of such heterogeneity or the nature of interaction between committee members.

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<sup>1</sup>See, for example, Chadha and Nolan (2001), Cobham (2002a, b, 2003), Gerlach-Kristen (2004), and Bhattacharjee and Holly (2005).

In the literature, there is some theoretical work highlighting sources of heterogeneity among policy makers. Backus and Driffill (1985) propose a model where central bank preferences are uncertain. They consider a infinite-horizon world with two types of policy makers; one type is strategic and maximizes social welfare while the other always chooses zero inflation. Sibert (2002) considers the situation where policy makers have varying and uncertain aversion to inflation relative to their dislike for output loss – this is a source of heterogeneity. Further, when policy makers serve in the committee for two periods, she shows how strategic behaviour can lead to different votes in the first and second periods. Bhattacharjee and Holly (2005), on the other hand, consider a committee setup where there are three distinct sources of uncertainty. First, committee members may differ about the effect of interest rates on output and inflation, because of which they obtain different policy rules. Second, members have access to different private information sets which also contributes to heterogeneity in their own policy rules. Heterogeneity due to these two sources are, however, averaged out through information sharing and deliberation within the committee. Third, because of uncertainty regarding the current and future states of the economy, the members also have different views on the size of the output gap and forecasts of inflation. Their empirical study of voting behaviour in the Bank of England’s Monetary Policy Committee (henceforth, MPC) shows that the nature of residual heterogeneity is well captured in their differing response to uncertainty in the macroeconomic environment.

There is also some recent theoretical literature suggesting strategic voting with monetary policy committees. In Sibert (2003), there are two types of policy maker. The first is "activist" (or opportunistic) and uses surprise inflation to signal toughness, while the second type of central banker is mechanistic and always votes for zero inflation. She shows that there are incentives for strategic behaviour. A new member will tend to signal toughness to gain credibility. Further, if the culture or rules of a central bank puts more weight on senior policy makers, a new member’s incentive to build a reputation is greater. Inflation-averse members ("doves") find less opportunity for reputation-building as compared with members who vote for higher interest rates more often ("hawks"). The work of Sibert (2003) provides a good framework for understanding the strategic behaviour of MPC members as revealed through their votes. Using residuals from an estimated model of individual votes that allows for heterogeneity in the effect of uncertainty, Bhattacharjee and Holly (2005) classify the 19 MPC members as being cau-

tious or activist (low or high error variance), and as hawks or doves (positive or negative individual-level fixed effects)<sup>2</sup>. However, there is little work on understanding the interdependencies between the decisions of different policy makers in a committee.

In this paper, we consider a monetary policy committee where personalities are important. In our model of committee decision making, the personalities are reflected in heterogeneity in the policy reaction functions for the different members, as well as in strategic interactions among members. We extend the work in Bhattacharjee and Holly (2005) by considering heterogeneity in the beliefs about the effects of interest rates on output and inflation, in the private information of each committee member and in their differing views on uncertainty. Further, we allow for interaction between the members of the committee.

As in Bhattacharjee and Holly (2005), our empirical exercise involves estimating policy reaction functions where the response variable (votes) is interval censored. The interval-censored residuals from the estimated individual-level reaction functions for 5 selected MPC members are then used to estimate a cross-sectional covariance matrix, using the Expectation-Maximisation (EM) algorithm. The magnitude and strength of interactions between policy decisions for the 5 MPC members is then assessed using methods for estimating spatial weights matrices proposed in Bhattacharjee and Jensen-Butler (2005).

The empirical study shows evidence of substantial heterogeneity in individual policy reaction functions within the Bank of England's MPC. We also find significant interdependence between monetary policy decisions of the different members. The nature of these interdependencies inform about information sharing and strategic interactions within the Bank of England's Monetary Policy Committee.

The plan of the paper is as follows. In section 2 we discuss our model of committee decisionmaking within a monetary policy committee. Our empirical model and econometrics are presented in Section 3, and in section 4 we report our empirical results. Finally, in section 5, we present our conclusions.

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<sup>2</sup>See also King (2002) and Gerlach-Kristen (2004).

## 2 Monetary Policy and Committee Decision Making

In this section, we discuss briefly some simple models of the inflation process and introduce a role for transparency and for a committee structure for decision-making and consider the signal extraction problem that the MPC and its members face individually. The model is broadly similar to Bhattacharjee and Holly (2005), with a modification to allow for inter-member interactions.

### 2.1 Inflation forecast targeting and interest rates

We adopt the most simple form of a model of the monetary policymaking process and abstract from many issues that have been the focus of much of the recent literature. We do this deliberately in order to have a model that appears to align best with how central banks view the monetary transmission process and to provide a justification for the way in which policy appears to be conducted.<sup>3</sup> The model is structured as follows:

$$\pi_t = \pi_{t-1} + \alpha y_{t-1} + \epsilon_t \quad (1)$$

$$y_t = \beta_1 y_{t-1} - \beta_2 (i_{t-1} - \pi_{t-1}) + \eta_t \quad (2)$$

$\pi_t$  is the inflation rate in period  $t$ ,  $y_t$  is the output gap (the difference between the log of output and the log of potential output),  $i_t$  is the nominal interest rate.  $\eta_t$  and  $\epsilon_t$  are iid shocks in period  $t$  not observable in period  $t - 1$ . The coefficients  $\alpha$  and  $\beta_2$  are positive;  $\beta_1$  ( $0 < \beta_1 < 1$ ) measures the degree of persistence in the output gap. The output gap depends negatively on the real lagged interest rate. The change in inflation depends on the lagged output gap. The output gap is normalised to zero in the long run.

These pure delays in the impact of the output gap on inflation and of interest rates on the output gap captures in the most straightforward way the central bankers' stylised model of the monetary transmission process. The modern generation of New Keynesian models with nominal inertia and imperfect competition still exhibit jumps in output and inflation in response

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<sup>3</sup>In particular, for expositional purposes we ignore forward-looking expectations and issues arising consequently from time inconsistency.

to shocks<sup>4</sup> which will blur the pure delays embodied in equations (1) and (2). The intertemporal loss function is:

$$L_t = \frac{1}{2} E_t \sum_{\tau=t}^{\infty} [\delta^{\tau-t} [(\pi_{\tau} - \pi^*)^2] + \lambda y_{\tau}^2]. \quad (3)$$

Here,  $E_t$  denotes expectations conditional on information available in period  $t$ .  $\pi^*$  is the inflation target, and  $\delta$  is the discount rate ( $0 < \delta < 1$ ). The policymaker minimises the present discounted value of squared deviations of inflation from its target and the output gap.  $\lambda$  is the weight the policymaker attaches to the output gap, with the weight on inflation normalised to unity.

We consider the special case of  $\lambda = 0$ , so the policymaker only targets inflation, and the central bank can (in expectation) use the current interest rate to hit the target for inflation two periods hence. So perfect controllability in this case allows the intertemporal problem to be written as a sequence of single period problems. In this case (Svensson, 1997)

$$L_t = \frac{1}{2} [\pi_{t+2|t} - \pi^*]^2, \quad (4)$$

where  $\pi_{t+2|t}$  is the forecast of inflation at time period  $t + 2$  based on information available in period  $t$ . The central bank minimises the squared deviation of the current two-year inflation forecast,  $\pi_{t+2|t}$ , from the target. The forecast of  $\pi_{t+2}$  at  $t$  is

$$\pi_{t+2|t} = \pi_{t+1|t} + \alpha y_{t+1|t} \quad (5)$$

and

$$y_{t+1|t} = \beta_1 y_{t|t} - \beta_2 (i_t - \pi_{t|t}), \quad (6)$$

where the subscript  $t|t$  indicates that current realisations of the output gap and inflation may well be imperfectly observed, and need to be forecasted.

So:

$$\pi_{t+2|t} = \alpha [\beta_1 y_{t|t} - \beta_2 (i_t - \pi_{t|t})] \quad (7)$$

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<sup>4</sup>See Corrado and Holly (2004) for an example in which inertia comes partly from habit persistence in household consumption.

Then the inflation ‘feed forward’ rule is

$$i_t = (\pi_{t|t} - \pi^*) + \frac{1}{\alpha\beta_2}\pi_{t+1|t} + \frac{\beta_1}{\beta_2}y_{t|t} \quad (8)$$

This satisfies the Taylor Principle since  $\partial i/\partial \pi > 1$ , as long as there is persistence in inflation. Although an explicit weight is not attached to output losses, current (forecasted) output appears in the rule because the current output gap is informative about future inflation. In Svensson’s original formulation  $\pi_{t|t}$  and  $y_{t|t}$  are known. In practice, as Orphanides (1998) has pointed out, in real time current inflation and the current output gap are not observed. For expositional purposes we are assuming that the decision period coincides with the observation period. In practice data are available at different frequencies from daily to yearly.

## 2.2 Heterogeneity and committee decision-making

We focus on a strict inflation targeting regime, preference heterogeneity is not meaningful. Instead we adopt the alternative approach in which heterogeneity arises from two different sources: (a) differing views about the state of the economy, leading do different views about the magnitude of the output gap, and (b) varying beliefs about the effect of interest rate on inflation and output gap ( $\alpha\beta_2$  and  $\beta_2$  respectively). With members subject to these two forms of heterogeneity, we present a model of committee decision making in a monetary policy committee. In the next subsection, we consider information processing with noisy signals, and consider heterogeneity in the effect of uncertainty of individual members’ policy reaction functions.

Members come to the committee with different judgments about the state of the economy<sup>5</sup>. Each member has the same public information set but augments this with private information. This can take different forms. An individual member may dissent from the consensus forecast or an individual member may have particular expertise that leads to more weight being attached to particular kinds of information compared to the average. Since

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<sup>5</sup>As King (2002) has pointed out, most of the discussion that takes place among the MPC members is focused on a technical economic judgment about what it is necessary to do to hit the inflation target. A sense of this process can be got from the summary of discussions in each MPC meeting discussed in Cobham (2003). Chadha and Nolan (2001) examine whether the perceived variation in preferences across MPC members (as revealed in their votes) is related to volatility in interest rates.

the internal dynamics of committee decision making can result in a measure of sharing of expertise (see Geanakoplos, 1992; Bicchieri, 1993), we shall assume that the decision of each individual member is ultimately based on commonly shared information as well as private views that cannot be shared fully with the other members of the MPC, or to which the other members of the Committee attach varying importance.

Following the growing game theoretic literature on committee decision making involving issues such as strategic voting, the acquisition of information, possible conflicts of interest, and how information is communicated in committees (see Gerling *et al.* (2003) for a recent survey), we think of the decision-making process by the MPC as a two-stage process. In this first stage there is deliberation about the state of the economy (Gerlach-Kristen, 2003; Meade and Stasavage, 2004), staff economists present conjunctural analyses of recent events, members share information and views and eventually a central forecast, with agreed error bands in the form of a fan chart, is arrived at. Nevertheless, at the second stage, despite this sharing of knowledge many MPC members will choose an interest setting different to the central estimate.

This process can be cast as a simple signal extraction problem. Once all public information is revealed and sharable private information of all the members are exchanged, each committee member formulates her own initial estimate of the output gap. This estimate is based on  $x_t^j$ , a  $g \times 1$  vector of variables that the  $j$ -th MPC member may take notice of (including all publicly available information, and shared private information contained in asset and labour market developments, for example), plus private views that cannot be shared with the rest of the committee. Then the underlying model is:

$$y_t^j = \beta_j \cdot x_t^j + \omega_t^j \text{ with } \omega_t^j \sim N(0, \sigma_{\omega^j}^2) \text{ and } E(y_t^j) = \beta_j \cdot x_t^j = y_t, \text{ for } j = 1, \dots, m. \quad (9)$$

*This member-specific initial estimate of the output gap (Equation 9) incorporates heterogeneity in the judgments about the state of the economy through different  $x_t^j$  for different members. Since  $\omega_t^j$  reflects private views not shared by other committee members, we would normally expect that  $E(\omega_t^j \cdot \omega_t^k) = 0$ , for  $j \neq k$ . However, in case there is strategic interaction between committee members  $j$  and  $k$ ,  $\omega_t^j$  and  $\omega_t^k$  can be correlated. The  $j$ -th variance term  $\sigma_{\omega^j}^2$  captures both objective and subjective confidence in the estimate of  $y_t$ 's.*

At the end of discussion and deliberation, an agreed estimate,  $y_t^b$ , of the output gap is agreed upon. This common estimate is a weighted average of the initial estimates for the  $m$  committee members. Therefore, this central bank estimate is unbiased for the true output gap with

$$y_t^b = y_t + \omega_t^b \text{ with } \omega_t^b \sim N(0, \sigma_{\omega^b}^2). \quad (10)$$

For the  $j$ -th member, the final estimate of  $y_t$  that minimises the forecast error variance and combines optimally the central bank estimate ( $y_t^b$ ) and the private estimate ( $y_t^j$ ) is given by:

$$y_t^{dj} = y_t^b + \kappa^j (y_t^j - y_t^b), \quad (11)$$

where  $y_t^{dj}$  is the final decision by the  $j$ -th member on what the best estimate of the output gap is, and  $\kappa^j$ , is the Kalman gain. *This final estimate* (Equation 11) *shows how members may differ about the size of the output gap, which is an important source of heterogeneity in our model*<sup>6</sup>.

In addition to heterogeneity in judgments about the state of the economy and the magnitude of the output gap, *committee members may also differ in their views on the effect of interest rates on inflation and output gap*. In the context of the interest rate model under inflation forecast targeting presented in the previous subsection, this implies member-specific effects  $\alpha_j \beta_{2j}$  and  $\beta_{2j}$  respectively. This form of heterogeneity is, in principle, similar to preference regarding the tradeoff between inflation and output loss (as in Sibert, 2002) in the general form of the policy maker's loss function (Equation 3).

Under the model of committee decision making presented above, and given the two types of heterogeneity, the decision rule for the  $j$ -th member can now be written as:

$$i_{jt} = (\pi_{t|t} - \pi^*) + \frac{1}{\alpha_j \beta_{2j}} \pi_{t+1|t} + \frac{\beta_1}{\beta_{2j}} y_{t|t} + \varsigma_{jt} \quad \text{for } j = 1, \dots, m, \quad (12)$$

where

$$y_{t|t} = y_t^b = \beta_j \cdot x_t^j + \omega_t^j$$

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<sup>6</sup>In the discussion of differing views of the MPC members in the September 2006 meeting of the MPC (Bank of England, 2006), there is explicit acknowledgement that different members place different weights on the same macroeconomic events and implicitly also that they may hold different views on the magnitude of the output gap.

is the central bank estimate (or forecast) of current output gap and

$$\varsigma_{jt} = \frac{\beta_1}{\beta_{2j}} \cdot \kappa^j \cdot (y_t^j - y_{t|t})$$

represents the effect of the deviation

$$(y_t^j - y_{t|t}) = (\omega_t^j - \omega_t^b)$$

of the  $j$ -th member's initial estimate of output gap from the common estimate.

Two important points must be noted regarding the nature of the  $\varsigma_{jt}$ 's. First,  $\varsigma_{jt}$  need not be a zero mean process and in general captures the extent to which the  $j$ -th member deviates from the central interest rate projection that is implied by the central bank forecast. Hence,  $\varsigma_{jt}$  can be expressed in fixed effects form as

$$\varsigma_{jt} = \phi_j + \gamma_{jt},$$

where the  $\gamma_{jt}$ 's are zero mean random errors.

Second,  $\varsigma_{jt}$ 's are uncorrelated across different meetings for the same policy maker, but are correlated across members of the committee. This is because: (a) they are related to each other through the common estimate of the output gap ( $y_{t|t}$ ) which in itself is a linear combination of the initial estimates for all the members of the committee, and (b) there may be strategic interactions among committee members, in which case  $E(\omega_t^j \cdot \omega_t^k) \neq 0$  for some  $j \neq k$ . An important contribution of this paper is in understanding the nature of cross-member interactions within the Bank of England's MPC.

### 2.3 Recursive information processing

In the previous subsection the signal extraction problem was cast as one in which individual members decide on their interest rate recommendation by combining optimally the common and the private estimate (or forecast) of the output gap. But it is also worthwhile to think of the process by which the signal is extracted as recursive. In particular, the MPC meets and makes decisions on a monthly basis. New information is analysed relative to what was known in the previous month. This is because in each month the MPC explicitly sets the interest rate at that level which it believes will achieve the

inflation target 18 months to two years into the future. It must therefore be the case that if no new (reliable) information is available about the state of the economy then interest rates will remain unchanged. Moreover, given that interest rates are only changed in multiples of 25 basis points, there has to be sufficient new information to trigger a change. The uncertainty regarding the new information and its likely impact on future states of the economy is obviously an important component in the process of information processing.

Following Bhattacharjee and Holly (2005), we cast the problem of determining  $y_{t|t}$  and  $\pi_{t+1|t}$  and implicitly the uncertainty associated with forecasts as an optimal filtering or signal extraction problem (Holly and Hughes Hallett, 1989). A detailed derivation of the model is described in Bhattacharjee and Holly (2005).

Here we simply note that the framework incorporates the time varying quality and reliability of new information. The central point from the perspective of monetary control is that the usefulness of new observations on the economy varies over time. In some periods there will be little if any revisions to the optimal estimates of  $y_{t|t}$  and  $\pi_{t+1|t}$ , so a change in the interest rate setting will not take place<sup>7</sup>. Information about the state of the economy appears more or less continuously if we are observing asset markets while other forms of information appear as discrete packages in the form of flash estimates of GDP, full sets of national accounts and regularly compiled forecasts.

We assume that this multivariate filtering is the domain of the Bank of England and the MPC. However, we can also allow for individual members of the MPC to optimally update their private forecasts. Assume that  $\varsigma_{jt}$  for each member follows an autoregressive process.

$$\varsigma_{jt} = \phi_j + \theta_j \varsigma_{j,t-1} + \gamma_{jt}, 0 < \theta_j < 1, \gamma_{jt} \sim N(0, \sigma_{\gamma_t}^2) \quad (13)$$

and we observe this via

$$z_{jt} = \varsigma_{jt} + \delta_{jt} \quad \text{with } \delta_{jt} \sim N(0, \sigma_{\delta_j}^2), \quad (14)$$

where now  $z$  is a scalar. Then the optimal private estimate for the  $j$ -th committee member is

$$\varsigma_{jt|t} = \varsigma_{jt|t-1} + [\sigma_{\gamma_t}^2 / (\sigma_{\gamma_t}^2 + \sigma_{\delta_j}^2)](z_{jt} - \varsigma_{jt|t-1}). \quad (15)$$

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<sup>7</sup>It may also be that interest rate setting by the MPC is affected by the frequency with which the central forecasts of the Bank of England are updated. The *Inflation Report* is published 4 times a year in February, May, August and November.

Of course, the revisions to private information will vary with the quality of new observations. Further, because the optimal private estimate for the  $j$ -th committee member also depends on  $\sigma_{\delta_j}^2$ , there will also be *heterogeneity in the effect of uncertainty across the different members*.

The standard separation of observation from control means that these optimal estimates of  $y_{t|t}$ ,  $\pi_{t+1|t}$  and  $\varsigma_{jt|t}$  can be plugged into the feedback rule given in equation (12)<sup>8</sup>. This implies a decision rule for the  $j$ -th member in the following form:

$$i_{jt} = (\pi_{t|t} - \pi^*) + \phi_j + \frac{1}{\alpha_j \beta_{2j}} \pi_{t+1|t} + \frac{\beta_1}{\beta_{2j}} y_{t|t} + \underline{\beta}_x^j \cdot \underline{x}_t^j + \beta_\sigma^j \cdot \sigma_{\gamma_t} + \vartheta_{jt} \quad \text{for } j = 1, \dots, m. \quad (16)$$

The various components of the model have important interpretations and implications:

1. The member-specific fixed effect  $\phi_j$  indicates whether the  $j$ -th member is a hawk (positive values) or a dove (negative values)
2.  $\underline{x}_t^j$  denotes the indicators included in the  $j$ -th member's initial estimate of the output gap and  $\underline{\beta}_x^j$  is the corresponding coefficient vector. There is heterogeneity both in the choice of the variables and in their effects.
3.  $\sigma_{\gamma_t}$  is a measure of the uncertainty associated with future macroeconomic climate and  $\beta_\sigma^j$  denotes the  $j$ -th member's response to such uncertainty. When there is more uncertainty regarding future (forecast) output gap and inflation, policy makers will be more hesitant to raise interest rates. However, different members in the committee differ in their response to this uncertainty. In the empirical work for the MPC, we use the standard deviation in one-year ahead forecast output growth (from the output growth fan charts published by the Bank of England) as the time-varying measure of uncertainty ( $\sigma_{\gamma_t}$ ).
4. Finally,  $\vartheta_{jt}$ 's are zero mean errors with a different variance for each member. The magnitude of the variance reflects how activist a particular member is. For member  $j$ ,  $\vartheta_{jt}$ 's are uncorrelated across meetings.

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<sup>8</sup>This separation also carries over to a more general model in which expectations are forward looking (Pearlman, 1992).

However,  $\vartheta_{jt}$ 's are correlated across members – the degree of correlation reflecting both the nature of deliberation within the committee for arriving at a common estimate of the output gap, and the degree of strategic interaction between members.

In contrast to the Federal Reserve<sup>9</sup> and the ECB, where decision making is by ‘consensus’, the Monetary Policy Committee of the Bank of England uses majority voting so it is the median vote that decides the outcome for monetary policy. Votes cast by individual policy makers, usually in multiples of 25 basis points, are published by the Bank of England. The decision that is actually implemented,  $\Delta i_t$ , is then a multiple of 25 basis points, and is the vote of the median member<sup>10</sup>.

As emphasized earlier, there are three main forms of heterogeneity in our model. First, members may differ in their views about the state of the economy, and thereby differ in their private estimates of the output gap. Second, there may be heterogeneity in the beliefs about how much effect interest rates may have on future inflation and/ or output. And thirdly, members may differ in their propensity to avoid changes in interest rates given uncertainty about future states of the economy.

In addition, our model allows for interaction between the monetary policy committee members, through information sharing over the decision making process, but also by way of strategic interaction among members. In the next section, we present our empirical model for monetary policy in the Bank of England’s MPC in more specific terms, and discuss our econometric strategy to uncover the nature of heterogeneity and interactions in the decision making process.

### 3 Data, Empirical Model and Estimation

In the previous section we presented a model of committee decision making based on an inflation forecast rule and accommodating heterogeneity across policy makers and interaction between their individual decisions. In

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<sup>9</sup>See Edison and Marquez (1998) for a detailed description of the decision making processes of the Federal Open Markets Committee.

<sup>10</sup>Strictly the voting is sequential, where the initial options are to raise, lower or the keep the interest rate unchanged. If a majority votes for no change there is no further voting. If the vote is for a change, either higher or lower, a vote is then needed on the magnitude of the change.

this section we turn to an empirical examination of decision making within the Monetary Policy Committee of the Bank of England. In the following subsections, we present our data and the empirical model, and discuss the econometric methods used to estimate the model.

### 3.1 Data and sample period

The primary objectives of the empirical study is to understand heterogeneity and interaction in decision making at the Bank of England’s MPC, within the context of the model of committee decision making presented in the previous section. Our dependent variables are the decisions of the individual members of the MPC. The source for these data are the minutes of the MPC meetings.

**TABLE 1: Voting records of selected MPC members**

Member	Meetings	Votes			Dissent		
		Lower	No change	Raise	Total	High	Low
Buiter	36	10	10	16	17	9	8
Clementi	63	14	39	10	4	3	1
George	74	15	51	6	0	0	0
Julius	45	18	25	2	14	0	14
King	85	14	50	21	12	12	0

Since mid-1997, when data on the votes of individual members started being made publicly available, the MPC has met once a month to decide on the base rate for the next month<sup>11</sup>. Over most of this period, the MPC has had 9 members at any time: the Governor (of the Bank of England), 4 internal members (senior staff at the Bank of England) and 4 external members. External members were usually appointed for a period ranging from 3 to 4 years. Because of changes in the external members, the composition of the MPC has changed reasonably frequently. To facilitate study of heterogeneity and interaction within the MPC, we focus on 5 selected members, including the Governor, 2 internal and 2 external members. The longest such period when the same 5 members have concurrently served in the MPC is the 33 month period from September 1997 to May 2000. The 5 MPC members who served during this period are: George (the Governor), Clementi and King (the 2 internal members) and Buiter and Julius (the 2 external members).

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<sup>11</sup>The MPC met twice in September 2001. The special meeting was called after the events of 09/11.

The voting pattern of these selected MPC members suggest substantial variation (Table 1)<sup>12</sup>.

In order to explain the observed votes of the 5 selected members, we collected information on the kinds of data that the MPC looked at for each monthly meeting. Not all of this information is made use of in this paper but the important issue was to ensure that we conditioned only on what information was actually available at the time of each meeting. Assessing monetary policy decisions in the presence of uncertainty about forecast levels of inflation and the output gap (including uncertainty both in forecast output levels and perception about potential output) requires collection of real-time data available to the policymakers when interest rate decisions are made as well as measures of forecast uncertainty. This contrasts with many studies of monetary policy which are based on realised (and subsequently revised) measures of economic activity (see Orphanides, 2003).

We collected information on unemployment (where this typically refers to unemployment three months prior to the MPC meeting, as well data on the underlying state of asset markets (housing prices, share prices and exchange rates). We measure unemployment by the year-on-year change in International Labor Organization (ILO) rate of unemployment, lagged 3 months. The ILO rate of unemployment is computed using 3 months rolling average estimates of the number of ILO-unemployed persons and size of labour force (ILO definition), both collected from the Office of National Statistics (ONS) Labour Force Survey. Housing prices are measured by the year-on-year growth rates of the Nationwide housing prices index (seasonally adjusted) for the previous month (Source: Nationwide). Share prices and exchange rates are measured by the year-on-year growth rate of the FTSE 100 share index and the effective exchange rate respectively at the end of the previous month (Source: Bank of England). The other current information included in the model is the current level of inflation – measured by the year-on-year growth rate of RPIX inflation lagged 2 months (Source: ONS).

Our model also includes expected rates of future inflation and forecasts of current and future output. One difficulty with using the Bank's forecasts of

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<sup>12</sup>For example, of the 45 meetings which Julius attended, the votes for 14 were against the consensus decision, and all of these were for a lower interest rate. On the other hand, King disagreed with the consensus decision in 12 of the 82 meetings he attended, voting for a higher interest rate each time. Buiters dissented in 17 meetings out of 36, voting on 8 occasions for a lower interest rate and 9 times in favour of a higher one. See also King (2002) and Gerlach-Kristen (2004).

inflation is that they are not sufficiently informative. By definition, the Bank targets inflation over a two year horizon, so it always publishes a forecast in which (in expectation) inflation hits the target in two years time. To do anything else would be internally inconsistent. Instead, as a measure of future inflation, we use the 4 year ahead inflation expectations implicit in bond markets at the time of the MPC meeting, data on which can be inferred from the Bank of England’s forward yield curve estimates obtained from index linked bonds<sup>13</sup>. For current output, we use annual growth of 2-month-lagged monthly GDP published by the National Institute of Economic and Social Research (NIESR) and for one-year-ahead forecast GDP growth, we use the Bank of England’s model based mean quarterly forecasts.

Finally, uncertainty in future macroeconomic environment and private perceptions about the importance of such uncertainty plays an important role in the model developed in this paper. The extent to which there is uncertainty about the forecast of the Bank of England can be inferred from the fan charts published in the Inflation Report. As a measure of uncertainty in the future macroeconomic environment, we use the standard deviation of the one-year-ahead forecast. These measures are obtained from the Bank of England’s fan charts of output; details regarding these measures are discussed elsewhere (Britton *et al.*, 1998). The forecasts of one-year-ahead output growth and its variance show substantial variation over time (Figure 1).

## 3.2 The empirical model

We start with the model of individual voting behaviour within the MPC developed in the previous section (Equation 16). The model includes individual specific heterogeneity in the fixed effects, in the coefficients of inflation and output gap, and in the effect of uncertainty. We aim to estimate this model in a form where the dependent variable is the  $j$ -th member’s preferred change in the (base) interest rate. In other words, our dependent variable,  $v_{jt}$ , represents the deviation of the preferred interest rate for the  $j$ -th member (at the meeting in month  $t$ ) from the current (base) rate of interest  $r_{t-1}$ :

$$v_{jt} = i_{jt} - r_{t-1}.$$

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<sup>13</sup>We use the four year expected inflation figure because the two year figure is not available for the entire sample period. In practice the inflation yield curve tends to be very flat after two years.

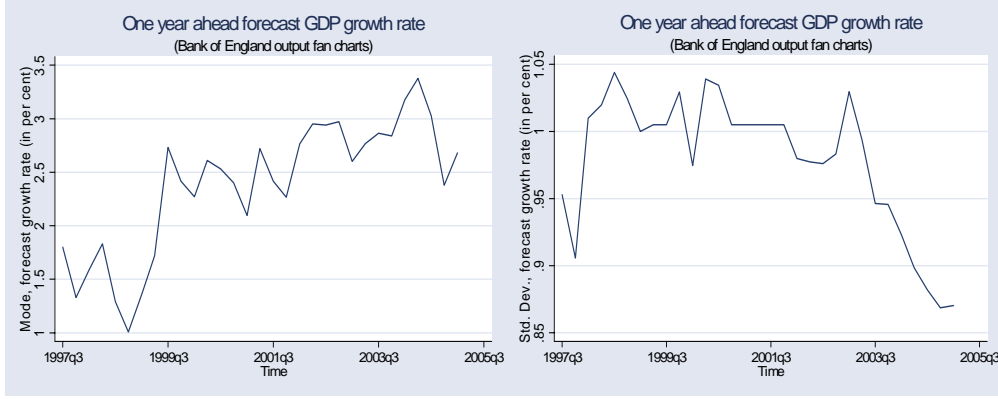


Figure 1: Variation in forecast output growth and its variance over time

Therefore, we estimate the following empirical model of individual decision making within the MPC:

$$v_{jt} = \phi_j + \beta_j^{(r)} \cdot \Delta r_{t-1} + \beta_j^{(\pi^0)} \cdot \pi_t + \beta_j^{(\pi^4)} \cdot \pi_{t+4|t} + \beta_j^{(y^0)} \cdot y_{t|t} + \beta_j^{(y^1)} \cdot y_{t+1|t} + \beta_j^{(\sigma)} \cdot \sigma(y_{t+1|t}) + \underline{\lambda}'_j \cdot \underline{Z}_t + \vartheta_{jt}, \quad (17)$$

where  $\underline{Z}_t$  represents current observations on unemployment ( $\Delta u_t$ ) and the underlying state of asset markets: housing, equity and the foreign exchange market ( $P_{hsg,t}$ ,  $P_{FTSE,t}$  and  $P_{exch,t}$  respectively). Standard deviation of the one-year ahead forecast of output growth is denoted by  $\sigma(y_{t+1|t})$ ; this term is included to incorporate the notion that the stance of monetary policy may depend on the uncertainty relating to forecast future levels of output and inflation. As discussed in the previous section, increased uncertainty about the current state of the economy will tend to bias policy towards caution in changing interest rates. In particular, this strand of the literature suggests that optimal monetary policy may be more cautious (rather than activist) under greater uncertainty in the forecast or real-time estimates of output gap and inflation (see Issing, 2002; Aoki, 2003; and Orphanides, 2003). Since, as previously discussed, the published inflation forecast is not sufficiently informative, we confined ourselves to uncertainty relating to forecasts of future output growth.

However, there are two important additional features of our data generating process that render the estimation exercise nonstandard. First, the

dependent variable is observed in the form of votes, which are highly clustered interval censored outcomes based on the underlying decision rules. Second, the regression errors are interrelated across the members.

### 3.2.1 Interval censored votes

Votes of MPC members are highly clustered, with a majority of the votes proposing no change in the base rate. The final decisions on interest rate changes are all similarly clustered. For the Bank of England’s MPC as a whole over the period June 1997 to March 2005, 69 per cent of the meetings decided to keep the base rate at its current level, 14 per cent recommended a rise of 25 basis points, 13 per cent recommended a reduction of 25 basis points, and 4 per cent a reduction of 50 basis points.

This clustering has to be taken into account when studying individual votes and committee decisions of the MPC. We do not observe changes in interest rates on a continuous or unrestricted scale, we have a non-continuous or limited dependent variable. Moreover, changes in interest rates are in multiples of 25 basis points. Therefore, following Bhattacharjee and Holly (2005), we use an interval regression framework for analysis; other authors have used other limited dependent variable frameworks, like the logit/ probit or multinomial logit/ probit framework to analyse monetary policy decisions (for recent contributions, see Chevapatrakul *et al.*, 2001, and Gascoigne and Turner, 2003). Our choice of model is based on the need to use all the information that is available when monetary policy decisions are made, as well as problems relating to model specification and interpretation of multinomial logit models (Greene, 1993). We also explored a multinomial logit formulation, and found the broad empirical conclusions to be similar.

Therefore, the observed dependent variable in our case,  $v_{jt,obs}$ , is the truncated version of the latent policy response variable of the  $j$ -th member,  $v_{jt}$ , which we model as

$$\begin{aligned}
 v_{jt,obs} &= -0.25 && \text{if } v_{jt} \in [-0.375, -0.20) \\
 &= 0 && \text{if } v_{jt} \in [-0.20, 0.20] \\
 &= 0.25 && \text{if } v_{jt} \in (0.20, 0.375], \text{ and} \\
 v_{jt} &\in (v_{jt,obs} - 0.125, v_{jt,obs} + 0.125] && \text{whenever } |v_{jt,obs}| > 0.325
 \end{aligned} \tag{18}$$

The wider truncation interval when there is a vote for no change in interest rates (*ie.*, for  $v_{jt,obs} = 0$ ) may be interpreted as reflecting the conservative

stance of monetary policy under uncertainty with a bias in favour of leaving interest rates unchanged.

### 3.2.2 Inter-relationship between regression errors

As discussed in the previous section, the regression errors,  $\vartheta_{jt}$ 's, are uncorrelated across different meetings for a given MPC member, but possibly correlated across members. The degree of correlation reflects both the nature of deliberation within the committee before arriving at a common estimate of the output gap, and the degree of strategic interaction between members. We represent the inter-relationship between the  $\vartheta_{jt}$ 's as a cross-section (spatial) autoregressive process as:

$$\vartheta_{jt} = \sum_{i \neq j} w_{ij} \vartheta_{it} + \psi_{jt} \quad \text{for } j = 1, \dots, m,$$

or

$$\underline{\vartheta}_t = \mathbf{W} \cdot \underline{\vartheta}_t + \underline{\psi}_t, \tag{19}$$

where  $\underline{\vartheta}_t = (\vartheta_{1t}, \vartheta_{2t}, \dots, \vartheta_{mt})'$ ,  $\mathbf{W}$  is a (spatial) weights matrix with zero diagonal elements

$$\mathbf{W} = \begin{bmatrix} 0 & w_{12} & \dots & w_{1m} \\ w_{21} & 0 & \dots & w_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ w_{m1} & w_{m2} & \dots & 0 \end{bmatrix}$$

such that  $(\mathbf{I} - \mathbf{W})$  is nonsingular ( $\mathbf{I}$  denotes the identity matrix), and  $\underline{\psi}_t = (\psi_{1t}, \psi_{2t}, \dots, \psi_{mt})'$  is a vector of uncorrelated errors that are possibly heteroscedastic with

$$E \left( \underline{\psi}_t \cdot \underline{\psi}_t' \right) = \Sigma = \begin{bmatrix} \sigma_1^2 & 0 & \dots & 0 \\ 0 & \sigma_2^2 & \dots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \dots & \sigma_m^2 \end{bmatrix}.$$

In combination with the regression model (Equation 17), the process of error propagation (Equation 19) describes a model known in the spatial

econometrics literature as the spatial error model with autoregressive errors (Anselin, 1988, 1999). The elements in the (spatial) weights matrix  $\mathbf{W}$  describe the strength of interaction between different MPC members. The purely idiosyncratic part in the policy reaction function of each member,  $\psi_{jt}$ 's, are derived from the private and unshared information that each member possesses. These idiosyncratic errors are uncorrelated across the members and are allowed to have different variances for different MPC members; the magnitude of the variance indicates how activist the member is.

We complete the description of the empirical model with a distributional assumption on the errors:

$$\underline{\psi}_t \sim N_m(\underline{0}, \Sigma),$$

where  $N_m$  denotes the  $m$ -variate normal distribution. Unlike standard practice within the spatial econometrics literature, the spatial weights matrix in our case is unknown. The objective of the econometric exercise will be to estimate separate policy reaction functions (Equation 17) for each of the 5 MPC members under study, and to estimate the spatial weights matrix,  $\mathbf{W}$ . The differences in the estimates of the policy reaction function across the different MPC members will indicate the degree of heterogeneity and the elements of the estimated spatial weight matrix will indicate the strength (and nature) of interaction.

### 3.3 Estimation

#### 3.3.1 Estimating the policy reaction function for each member

Under the maintained assumptions that (a) regression errors are uncorrelated across meetings, and (b) the response variable is interval censored, estimation of the policy reaction function for each member (Equation 17) is a straightforward application of interval regression. The interval regression model (Amemiya, 1973) is a generalisation of the tobit model where the truncation in the dependent variable is possibly different for different observation units, and the truncation cut-offs are known. Estimates are available in standard econometrics packages – we use STATA for estimation.

#### 3.3.2 Estimation of the spatial weights matrix and error variances

In the literature, the spatial weights matrix is usually considered known *a priori*. In our application, however, we wish to estimate the spatial weights

matrix and use the estimates to understand the nature of cross-member interaction.

Bhattacharjee and Jensen-Butler (2005) have recently proposed a method to estimate the spatial weights matrix under a spatial error model with autoregressive spatial errors. Their method starts with obtaining a consistent estimate,  $\widehat{\Gamma}$ , of the cross-member covariance matrix of the regression errors

$$E\left(\underline{v}_t.\underline{v}_t'\right) = \mathbf{\Gamma} = (\mathbf{I} - \mathbf{W})^{-1}.\mathbf{\Sigma}.\left(\mathbf{I} - \mathbf{W}\right)^{-1'}.$$

Given this consistent estimate of the error covariance matrix, they show that upto an orthogonal transformation, the matrix

$$\mathbf{V} = (\mathbf{I} - \mathbf{W})' .diag\left(\frac{1}{\sigma_1}, \frac{1}{\sigma_2}, \dots, \frac{1}{\sigma_m}\right) \quad (20)$$

is consistently estimated by the inverse of the symmetric square root of the estimated covariance matrix  $\widehat{\Gamma}$ <sup>14</sup><sup>15</sup>. In other words,  $\widehat{\Gamma}^{-1/2}.\mathbf{T}$  is a consistent estimator of  $\mathbf{V}$  for some unknown square orthogonal matrix  $\mathbf{T}$ .

Suppose, we knew the orthogonal matrix  $\mathbf{T}$ . Then, Bhattacharjee and Jensen-Butler (2005) show that the error variances can be estimated as

$$\widehat{\sigma}_j^2 = \frac{1}{q_{jj}^2}, \quad j = 1, \dots, m \quad (21)$$

and the spatial weights matrix as:

$$\widehat{\mathbf{W}} = \begin{bmatrix} 0 & -q_{21}/q_{22} & \dots & -q_{K1}/q_{KK} \\ -q_{12}/q_{11} & 0 & \dots & -q_{K2}/q_{KK} \\ \vdots & \vdots & \ddots & \vdots \\ -q_{1K}/q_{11} & -q_{2K}/q_{22} & \dots & 0 \end{bmatrix}, \quad (22)$$

where the  $q_{ij}$ 's are the elements of the matrix

$$\mathbf{Q} = \widehat{\Gamma}^{-1/2}.\widehat{\mathbf{T}} = ((q_{ij}))_{i,j=1,\dots,m}.$$

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<sup>14</sup>The inverse of the symmetric square root, denoted  $\widehat{\Gamma}^{-1/2}$ , is the matrix  $\widehat{\Gamma}^{-1/2} = \widehat{\mathbf{E}}.\widehat{\mathbf{\Lambda}}^{-1/2}.\widehat{\mathbf{E}}^T$ , where  $\widehat{\mathbf{E}}$  and  $\widehat{\mathbf{\Lambda}}$  contain the eigenvectors and eigenvalues respectively of the estimated covariance matrix  $\widehat{\Gamma}$ .

<sup>15</sup>Here,  $diag(a_1, a_2, \dots, a_m)$  denotes a diagonal matrix with diagonal elements  $a_1, a_2, \dots, a_m$ .

Typically, one would then require either  $m(m-1)/2$  constraints, or equivalently an appropriate objective function to fix the orthogonal transformation. Bhattacharjee and Jensen-Butler (2005) show that an useful set of constraints is symmetry of the spatial weights matrix  $\mathbf{W}$ . This constraint is, however, not useful in our case since we expect the strength of interaction between MPC members often to be asymmetric. For example, it is plausible that an external member of the MPC arrives at her estimate of the output gap quite independently of what an internal member does, while the internal member may position himself strategically after assessing how the external member is likely to vote.

We, therefore, build up an alternative set of  $m(m-1)/2 = 10$  constraints. In the first instance, our constraints include

- **Row standardisation:** It is quite common in the spatial econometrics literature to work with a row standardised spatial weights matrix, where the rows sum to unity. This, however, is not strictly relevant in our context because some of the elements in the spatial weights matrix could be negative. Instead, we standardise rows so that the squares of the elements in each row sum to unity. This assumption gives us 5 constraints.
- **Homoscedasticity:** Initially, we also assume that the idiosyncratic errors have the same variance for each member:  $\sigma_1^2 = \sigma_2^2 = \dots = \sigma_m^2$ . This assumption gives a further 4 constraints. The homoscedasticity assumption may be too restrictive, and we relax this assumption later on.
- We choose symmetry between the spatial weights for the two internal members (Clementi and King) as the final required constraint.

We experimented with several alternative specifications of the 10 required constraints and the above appeared to be a good set of constraints to start with. The homoscedasticity constraint was, however, observed to be too restrictive. We relaxed this assumption subsequently, replacing these by suitable symmetry assumptions. In the next section, we discuss our assumptions in more detail.

Having fixed a set of appropriate constraints, the problem is one of choosing a suitable orthogonal matrix  $\mathbf{T}$ . Jennrich (2001) has recently proposed a “gradient projection” algorithm for optimising any objective function over

the group of orthogonal transformations of a given matrix. The only conditions necessary for implementing the algorithm are that (a) the objective function is differentiable, and (b) there exists a stationary point of the objective function within the class of orthogonal transformations. The gradient projection algorithm is simple to implement, once the partial derivatives of the objective function with respect to the elements of the orthogonal matrix  $\mathbf{T}$  can be analytically written down. For some objective functions, however, this may be difficult. In these circumstances one can then use numerical derivatives to find the optimising orthogonal transformation (Jennrich, 2004).

For example, one can optimise with respect to the set of constraints proposed above using the the objective function

$$\begin{aligned}
f(\mathbf{T}) &= \sum_{i=1}^5 q_{ii}^2 + \sum_{i=1}^4 \sum_{j=i+1}^5 q_{ii} \cdot q_{jj} && \text{(Homoscedasticity, 4 constraints)} \\
&+ A \cdot \sum_{i=1}^5 \left[ \sum_{j=1; j \neq i}^5 \frac{q_{ji}}{q_{jj}} - 1 \right]^2 && \text{(Row-standardisation, 5 constraints)} \\
&+ B \cdot \left( \frac{q_{32}}{q_{33}} - \frac{q_{23}}{q_{22}} \right)^2, && \text{(Symmetry, 1 constraint).}
\end{aligned}$$

where  $A$  and  $B$  are fixed positive scalars. Note that, row/ column 1 corresponds to the Governor (Eddie George) of the Bank of England, row/ columns 2 and 3 represent the internal members (Clementi and King) and 4 and 5 represent external MPC members (Buiter and Julius).

The gradient matrix is then given by

$$\frac{df}{d\mathbf{T}} = \hat{\Gamma}^{-1/2} \cdot \mathbf{G},$$

where  $\mathbf{G} = ((g_{ij}))_{i,j=1,\dots,5}$  is the matrix of derivatives of the objective function

with respect to  $\mathbf{Q}$ , with

$$\begin{aligned}
g_{ii} &= 3q_{ii} - \sum_{j=1}^5 q_{jj} - \frac{2A}{q_{ii}^2} \cdot \sum_{j=1; j \neq i}^5 \left[ q_{ij} \cdot \left( \sum_{k=1; k \neq j}^5 \frac{q_{kj}}{q_{kk}} - 1 \right) \right] \\
&\quad - \mathbf{I}_{(i=2)} \cdot \frac{2B}{q_{ii}^3} \cdot q_{23} \cdot \left[ q_{23} - q_{32} \cdot \frac{q_{22}}{q_{33}} \right] - \mathbf{I}_{(i=3)} \cdot \frac{2B}{q_{ii}^3} \cdot q_{32} \cdot \left[ q_{32} - q_{23} \cdot \frac{q_{33}}{q_{22}} \right] \\
g_{ij} &= \frac{2}{q_{ii}} \cdot \left( \sum_{k=1; k \neq j}^5 \frac{q_{kj}}{q_{kk}} - 1 \right) \\
&\quad + \mathbf{I}_{(i=2, j=3)} \cdot \frac{2B}{q_{22}} \cdot \left( \frac{q_{23}}{q_{22}} - \frac{q_{32}}{q_{33}} \right) + \mathbf{I}_{(i=3, j=2)} \cdot \frac{2B}{q_{33}} \cdot \left( \frac{q_{32}}{q_{33}} - \frac{q_{23}}{q_{22}} \right)
\end{aligned}$$

and  $\mathbf{I}$  here denotes the indicator function. The gradient matrix for other sets of constraints can be similarly obtained.

Construction of confidence bounds and testing for the estimates of spatial weights and the idiosyncratic error variances can be conducted using the bootstrap<sup>16</sup>.

### 3.3.3 Estimating the cross-member error covariance matrix

The above method for estimating the spatial weights and idiosyncratic error variances is based on a consistent estimator for the regression error covariance matrix  $\mathbf{\Gamma} = E \left( \vartheta_t \cdot \vartheta_t' \right)$ . If we had a standard regression model, we could construct the matrix simply using residuals from the estimated regression.

In our case, however, the problem is nonstandard. Here, we cannot obtain residuals in the usual sense, since the response variable is interval censored. For example, suppose the observed response for the  $j$ -th member in a given month  $t$  is 0.25. By our assumed censoring mechanism (18), this response is assigned to the interval  $(0.20, 0.375]$ . Suppose also that the linear prediction of the policy response, based on estimates of the interval regression model is  $\hat{v}_{jt} = 0.22$ . Then the residual  $v_{jt} - \hat{v}_{jt}$  cannot be assigned a single numerical value, but can be assigned to the interval  $(0.20 - 0.22, 0.375 - 0.22]$ . In other words, the residual is interval censored:  $v_{jt} - \hat{v}_{jt} \in (-0.02, 0.155]$ .

Given such interval censored residuals, we propose estimation of the cross-member covariance matrix using the Expectation-Maximisation algorithm

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<sup>16</sup>Bhattacharjee and Jensen-Butler (2005) propose a bootstrap procedure when estimation of the regression model requires instrumental variables. In our case, however, the bootstrap is more straightforward.

(Dempster *et al.*, 1977; McLachlan and Krishnan, 1997). At the outset, we assign the residuals to the midpoint of the respective intervals and obtain an initial estimate of the covariance matrix.

Given this estimated covariance matrix, we can invoke the Expectation step of the EM algorithm and obtain expected values of the residuals given that they lie in the respective intervals. For each monthly meeting, therefore, we have to obtain conditional expectations by integrating the pdf of the 5-variate normal distribution with the given estimated covariance matrix. Numerically, this exercise can be quite intensive. Instead, we take a sampling approach by simulating a large number (in our case, 100,000) iid responses from the 5-variate normal distribution with the given covariance matrix and a zero mean vector. We then take the average of all the responses for which all the 5 random observations lie within their respective censoring intervals, and proceed to the Maximisation step.

The Maximisation step is simple. The MLE of the mean vector and covariance matrix for the 5-variate normal distribution is given simply by the sample mean and sample covariance matrix. These estimated parameters form the basis for the Expectation step in the next iteration.

This iterative process is continued till convergence. At convergence, the current estimate of the covariance matrix is the MLE for the covariance matrix of the interval censored residuals.

We can, then, use this estimated covariance matrix to infer whether the errors are correlated across members, as well as use the matrix to estimate the spatial weights and idiosyncratic error variances. Further, the estimated covariance matrix can also be plugged into a GLS type procedure to obtain asymptotically efficient estimates of the member-specific policy reaction functions. We, however, do not take this GLS step because the interval regression estimates of the policy reaction functions for the 5 MPC members under consideration is quite satisfactory.

## 4 Results

Now, we use the methods presented in the previous section to estimate the parameters of the empirical model, comprising the policy rule (Equation 17), interval censoring scheme (18) and interactions described by autoregressive spatial errors (19). The objective of the exercise is to study heterogeneity and interaction in the decision making process within the Bank of England's

Monetary Policy Committee.

## 4.1 Estimated policy rules and heterogeneity

Table 2 presents interval regression estimates and goodness-of-fit measures for the policy reaction functions for the 5 selected MPC members. The estimates are based on the empirical model (17) along with the interval censoring scheme (18).

**TABLE 2: Interval Regression Estimates of policy reaction functions for the 5 MPC members**

Variables	GOVERNOR	INTERNAL		EXTERNAL	
	George	Clementi	King	Buiter	Julius
$\Delta r_{t-1}$	-0.119	-0.107	-0.101	-0.164	-0.226*
$\pi_t$	0.040	0.024	-0.050	0.051	0.110
$\pi_{t+4 t}$	0.103**	0.110**	0.111**	0.258**	0.248**
$y_t$	-0.016	-0.024	-0.052	-0.114	0.046 <sup>+</sup>
$y_{t+1 t}$	0.211**	0.223**	0.186**	0.216*	0.047
$\Delta u_t$	-0.175	-0.244 <sup>+</sup>	-0.216 <sup>+</sup>	-0.645**	-0.251**
$P_{hsg,t}$	1.760**	1.696*	2.355**	6.154**	1.323
$P_{FTSE,t}$	0.620**	0.412 <sup>+</sup>	0.614**	1.229**	-0.222
$P_{exch,t}$	0.003	0.009	0.007 <sup>+</sup>	-0.006	0.004
$\sigma(y_{t+1 t})$	-1.152*	-0.420	0.378	-0.555	-0.981*
constant	-0.054	-0.795	-1.313**	-1.803	-0.716
Number of meetings	73	62	94	35	45
Good. of fit Wald $\chi^2$	141.4	148.4	174.6	458.5	911.7
Prob. > $\chi^2(10)$	0.000	0.000	0.000	0.000	0.000
Log pseudo-likelihood	-37.98	-38.57	-66.17	-27.89	-11.70

\*\* , \* and <sup>+</sup> - Significant at 1%, 5% and 10% level respectively.

It is clear that expected inflation and expected output matter for the interest rate decisions of most MPC members; currently observed inflation and output play a much less important role. This confirms the assertion of Section 2 that the Bank of England follows an inflation forecast regime. It is also noticeable that unemployment matters for most of the members, as do movements in the stock market and the housing market. The effect of the exchange rate is, however, not significant. The impact of output uncertainty is negative for all the members, and significant for George (the Governor) and

Julius. Similar observations were made in Bhattacharjee and Holly (2005) based on interval regression estimates for the aggregate monetary policy decision.

More importantly, the results highlight heterogeneity in the decision making process across the 5 MPC members. In particular, there is heterogeneity in the individual beliefs on the effect of inflation on interest rates and output. The estimates indicate that the external members (Buiter and Julius) believe in a lower effect of interest rates on inflation, and Julius's estimated policy function also indicates a higher effect on output. Thus these 2 external members appear to have a greater dislike for output loss than other members of the committee. Similarly, substantial heterogeneity is also observed in the perceived effect of unemployment, and of the stock and housing markets. Further, Table 2 indicates heterogeneity in the effect of output uncertainty, as well as in the individual-level fixed effects.

In summary, the presence of substantial heterogeneity in the policy reaction functions indicate that monetary policy decision making within a committee is more complicated than what can be inferred from an analysis of simple aggregate decisions undertaken in the literature.

## 4.2 Spatial weights and idiosyncratic error variances

As discussed in the previous section, we obtain interval censored residuals using estimates of the individual level policy reaction functions reported in Table 2. Using these residuals and an initial approximate estimate of the cross-member error covariance matrix, we invoke the EM algorithm to obtain the MLE. The iterative estimation procedure converges quite fast (in 4 iterations). The estimated covariance matrix and the implied correlation matrix for the regression errors across the 5 selected members are reported in Table 3.

The estimated correlation matrix in Table 3 indicate very high correlation coefficients between regression errors corresponding to several pairs of MPC members. This indicates that there is significant cross-member interdependence. Estimation of the spatial weights matrix would facilitate understanding of these interactions.

As discussed in the previous section, the estimator of the spatial weights matrix consistent with the observed covariance matrix is consistent only upto an orthogonal transformation. Therefore, we require several (10) restrictions to pin down the appropriate orthogonal matrix. We impose these restrictions

in several steps progressively relaxing the more critical assumptions and at the same time identifying restrictions that are consistent with the data.

**Table 3: Estimated MLEs for Mean Vector, Covariance Matrix and Correlation Matrix of Regression Errors (n = 33 months)**

A. REGRESSION ERRORS: MEAN VECTOR (MLE)

	<b>George</b>	<b>Clementi</b>	<b>King</b>	<b>Buiter</b>	<b>Julius</b>
	0.0041	-0.0174	-0.0070	0.0016	-0.0054

B. REGRESSION ERRORS: COVARIANCE MATRIX (MLE)

	<b>George</b>	<b>Clementi</b>	<b>King</b>	<b>Buiter</b>	<b>Julius</b>
<b>George</b>	.00829				
<b>Clementi</b>	.00923	.01031			
<b>King</b>	.00843	.00938	.00871		
<b>Buiter</b>	.00769	.00867	.00787	.00778	
<b>Julius</b>	.00106	.00112	.00108	.00058	.00050

C. REGRESSION ERRORS: ESTIMATED CORRELATION MATRIX

	<b>George</b>	<b>Clementi</b>	<b>King</b>	<b>Buiter</b>	<b>Julius</b>
<b>George</b>	<b>1.00</b>				
<b>Clementi</b>	0.9989	<b>1.00</b>			
<b>King</b>	0.9923	0.9896	<b>1.00</b>		
<b>Buiter</b>	0.9573	0.9679	0.9558	<b>1.00</b>	
<b>Julius</b>	0.5184	0.4934	0.5182	0.2965	<b>1.00</b>

At the first instance, we estimate the spatial weights matrix and idiosyncratic error variances under (1) 5 row-standardisation restrictions, (2) 4 restrictions on variances implying homoscedasticity in the idiosyncratic errors, and (3) a restriction that the weights between internal members (Clementi-King and King-Clementi) are the same. Estimates under the above restrictions, however, indicate that error variances for King and Julius may be larger than the other three MPC members. At the same time, estimates indicate that some of the other spatial weights, particularly those between the Governor and the internal members may be symmetric.

After experimenting with some other sets of assumptions, we finally pin down an orthogonal matrix consistent with the following sets of restrictions:

1. ROW-STANDARDISATION: Squares of elements in every row sum to unity (5 restrictions)

2. **HOMOSCEDASTICITY:** Idiosyncratic error variances are the same for George, Clementi and Buiter, and different and unequal error variances for King and Julius (2 restrictions)
3. **SYMMETRY:** Symmetric weights between the internal members and the Governor:  $w_{\text{Clementi,King}} = w_{\text{King,Clementi}}$ ,  $w_{\text{George,Clementi}} = w_{\text{Clementi,George}}$  and  $w_{\text{George,King}} = w_{\text{King,George}}$  (3 restrictions).

The estimates of the spatial weights and idiosyncratic error variances are presented in Table 4. As one can see, the restrictions are approximately satisfied. More importantly, confidence intervals based on the bootstrap indicate that quite a few of the spatial weights are significant.

As discussed earlier, non-zero spatial weights in our model are indicative of (a) interaction due to deliberation and combined decision making within the MPC, and/ or (b) strategic interaction. Of particular significance are the negative spatial weights. While the process of discussion and agreement to a common estimate of the output gap would contribute to positive spatial weights, negative weights are almost certainly the outcome of strategic interaction. In this context, the negative spatial weights between the Governor and the external members (Buiter and Julius) are of particular importance. It would appear that the evidence from these estimates point towards strategic alignment of votes within the MPC.

**Table 4: Estimated Spatial Weights Matrix**

	<b>George</b>	<b>Clementi</b>	<b>King</b>	<b>Buiter</b>	<b>Julius</b>	Row SS
<b>George</b>	<b>0</b>	0.642**	0.602**	-0.284**	-0.343**	<b>0.973</b>
<b>Clementi</b>	0.638**	<b>0</b>	-0.600**	0.261*	0.277**	<b>0.911</b>
<b>King</b>	0.618**	-0.608**	<b>0</b>	0.265*	0.322**	<b>0.926</b>
<b>Buiter</b>	-0.562**	0.562**	0.542**	<b>0</b>	-0.297	<b>1.014</b>
<b>Julius</b>	-0.564*	0.564*	0.555*	-0.249	<b>0</b>	<b>1.007</b>
$\hat{\sigma}_j$	$2.74e - 4$	$2.97e - 4$	$1.32e - 3$	$3.18e - 4$	$1.63e - 3$	

\*\* , \* and + - Significant at 1%, 5% and 10% level respectively.

In summary, our empirical study of the decision-making process within the Bank of England's MPC supports the economic model presented in this paper and indicates several interesting features. We find substantial heterogeneity in the policy reaction functions across different members in the MPC. There is heterogeneity in the beliefs about the effect of interest rates

on inflation and output, on the role of unemployment and asset markets, as well as on the effect of uncertainty in the future macroeconomic climate on interest rate decisions.

In addition we find evidence of interaction between the MPC members. Such cross-member interaction is due both to the process of deliberation and information sharing within the process of committee decision making, as well as to strategic behaviour of the policy makers.

## 5 Conclusions

In this paper we have considered committee decision making within a monetary policy committee that targets the two-year ahead inflation forecast. Our economic model suggests that we may find a wide variety of heterogeneity across the policy makers. Our model also suggests that voting behaviour across the committee may be interrelated in several ways. While part of the interactions may be due to discussion and deliberation within the committee, it is not unlikely to find strategic interaction between committee members.

Our empirical study of voting behaviour within the Bank of England's MPC provides good support for our theoretical model, and uncovers new evidence on the process of monetary policy decision making. In particular, we provide more extensive evidence on the nature of heterogeneity within the monetary policy committee. Further, our empirical investigation of the strength of cross-member interactions is new and provides valuable insight on the process of decision making within the MPC.

Our estimates of the policy reaction functions of several selected members confirms the common assumption that inflation forecast targeting is the domain of the Bank of England. At the same time, unemployment, as well as stock and housing market conditions have an important bearing on the interest rate decisions.

Further, we observe substantial heterogeneity in the estimated reaction functions across different members. In particular, the external members of the MPC have a lower aversion to inflation, as compared to their dislike for output loss or their preference for interest rate stabilisation. Different MPC members also react differently to uncertainty in the macroeconomic environment, to unemployment and to the asset markets. Such heterogeneity is important in understanding the process of monetary policy decision making.

In addition, we find substantial interactions across the members in the way that they vote on interest rate changes. While part of this interaction can be explained by discussion and information sharing within the decision making process at the MPC, we find evidence that some of the voting behaviour may be strategic. This issue requires further examination within the context of appropriate theory on incentives and strategic behaviour within a monetary policy committee. The emerging theoretical literature in this area (see, for example, Sibert, 2002, 2003 and references therein) may provide interesting new insights on this aspect.

To the extent that both heterogeneity and interactions reflect personalities of the policy makers, it would thus be too simplistic to argue that the monetary policy committee can be effective in taking personalities out of the decision making process. At the same time, it is evident from our model that heterogeneity across committee members has the advantage of providing opportunities to consider and debate a wide range of possible policy responses to current and expected future macroeconomic conditions. However, we also find evidence of strategic interactions between policy makers in the MPC. This evidence would cast some doubt on the notion that committee decisions enhance social welfare. Further theoretical and empirical work would have to be undertaken before such welfare considerations can be rigorously made.

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