CENTRAL BANKS' FORECASTS AND THEIR BIAS: EVIDENCE, EFFECTS AND EXPLANATION

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1. INTRODUCTION

This research is stimulated by the empirical observation that long-term inflation forecasts published by central banks which target inflation tend to be biased towards the target. To explain this we examine how the voting behaviour of members of a monetary policy committee (*MPC*) may influence its ability to targeting inflation. While the subject of the influence of decisions taken by the *MPC* on macroeconomic stability is well researched, relatively little is known about the effects of the intra-committee dynamics of *MPC*'s on future inflation. It is hypothesized here that the manner in which *MPC*'s make decisions, including individual preferences and interactions between *MPC* members, affect the decisions themselves and the subsequent outcomes. More precisely, the hypotheses are [1] bias might result from direct or indirect pressure from the leading members of the *MPC* on the forecasters, so that the long-term goals of the monetary policy appear to be feasible; [2] voting of the *MPC* members regarding policy decisions based on such biased forecasts might result in undertaking unnecessarily active decisions, which in turn lead to an increased volatility and persistence of inflation. Additionally, we aim to further the findings of Fritsche *et al.* (2015) and Fildes (2015), that organisational and psychological factors affect the rationality of forecasters' behaviour, by explaining the possible outcomes of such behaviour.

The effect of *MPC*'s decisions on macroeconomic stability has been widely analysed in the literature. Earlier research has looked at the preferences of committees with regards to inflation and output gaps e.g. Rogoff (1985), Waller (1989) and Mihov and Sibert (2006), along with the optimal rules to follow to ensure stability and growth, e.g. Rudebusch (2001) and Clarida *et al.* (2000) and how action are interpreted by the private sector e.g. (Demertzis and Hughes Hallett, 2008). This literature, however, has not usually considered the process by which the monetary decision is made. A smaller body of work has shown that the dynamics of group interactions

within *MPC*'s have a significant effect on their ability (e.g. Blinder and Morgan, 2005). These papers, examining heterogeneous voting behaviour under specific voting schemes, have principally been concerned with the real policy effects (Gerlach-Kristen, 2006), informational efficiency (Blinder, 2007), or game-theoretical equilibrium (Berk and Bierut, 2005a,b, 2010). The structure and heterogeneity of signals considered by the *MPC* members in their voting decision, however, has rarely been discussed. The relevant papers looking at this aspect of the problem are that of Gerlach-Kristen (2006) and Weber (2010), who both analyse the effect of different gap signals on voting (see also Blinder, 2007), Brooks *et al.* (2007), where dynamic behaviour of the *MPC* voters is considered, and Gerlach-Kirsten (2004, 2005), Horváth *et al.* (2010) and Sirchenko (2011), who use records of *MPC* voting to predict interest rate changes. We focus here on the effect of the *MPC* on inflation; however, historically central banks have also targeted exchange rates with varying degrees of success (Brandner *et al.* 2006). If these interventions are decided by committee they may be subject to the same types of biases we analyse here.

As in Weber (2010) we are assuming heterogeneity of the *MPC* members with respect to the signals they received. However, we concentrate on the heterogeneity of the inflationary rather than output gap signals. We follow Blinder's (2007) suggestion and consider the static and dynamic effects of such heterogeneity on *MPC* monetary decisions and, subsequently, on inflation. More precisely, this paper concentrates on those aspects of *MPC* voting behaviour which are related to the perception and manipulation of the inflation forecasts signals. We investigate the effect of bias resulting from alteration of the forecast signals before they reach the majority of the voters (for a different view on leaders' bias of the voting scheme see Chappell *et al.*, 2007). In many cases the experts who produce the forecasts for the *MPC* work under some institutional influence of the *MPC* members, e.g. they might be employed by the Central Bank and be subordinates of the chair of the *MPC* (who is often a Governor of the

Bank). As such it is possible for some members of the *MPC* to pressurise experts in such a way that they would produce forecasts which would suit the preferences of some members of the *MPC* more than the others. This would create a certain bias affecting voting outcome and, consequently, future monetary policy and inflation.

We examine the nature and outcomes of this potential bias using an inter-temporal model of voting. An evident difficulty in such research is the lack of data. Empirical information on individual votes are sometimes available and used for establishing relationships between voting and outcome; see e.g Chappell *et al.* 2005 and Brooks *et al.*, 2007). There is, quite understandably, no direct evidence of inflation signal manipulation. Nevertheless, some indirect empirical evidence has been found and is discussed in Section 2. Another difficulty is that analytical solutions in a fully stochastic and intertemporal context are intractable (see Section 4 of this paper). In the light of these, we resort to setting up an inter-temporal simulation model.

In this model decisions undertaken by the *MPC* directly affect next-period inflation. The crucial aspect of the model is the ability of one member of the committee to alter the inflation forecast signals delivered to the others (see Section 3). We assume that the most influential member of the committee has the power to alter the signals which other members of the committee receive.

An alternative description of this behaviour could be that the most dominant member influences more junior members' *perception* of an accurate signal. Regardless of whether this comes through force of argument, seniority, or institutional rules, the dominant member may persuade others to vote in a particular manner even when their individual interpretation of the signal would entail a different action. In this setting Sibert (2003) shows that if more weight is placed on the decisions of senior policy makers the change in expected social welfare is ambiguous.

The results presented in this paper may also be interpreted in the light of this setting and demonstrate that bias towards one particular policy maker has a specific effect on the ability to meet inflation targets.

The general model setting differs markedly from those usually applied in the contemporary theory of voting and aggregation rules. The initial assumptions are simple: the *MPC* members are sincere (naïve) voters, refraining from strategic voting. Only under the extreme assumption of independence of voting decisions and identical (for all voters) probabilities of taking the correct decision, together with particular voting scheme designs, can the voting process be regarded as optimal in the Condorcet sense (that is that sincere democratic majority voting on a limited number of alternatives is socially superior in relation to other alternatives; see e.g. Austen-Smith and Banks, 1996, Ladha, 1992, Chwe, 2010). Our work also relates to that of Dietrich and List (2004) who present a model in which jurors make decision based on a common body of evidence rather than the state of the world. It was shown in this paper that in the limit the probability of a correct decision converges to the probability of the evidence not being misleading. The model presented in this paper sits between these two views. Whilst our committee members receive information on a body of evidence rather than the state of the world, that body of evidence is not common. In fact the information reaching particular *MPC* members are partially stochastic, hence different and, in the general case, correlated. Nitzan and Paroush (1984) consider interdependent voting and find that it is inferior to independent voting. In contrast Estlund (1994) finds that in some circumstances voters may follow opinion leaders and increase overall competence.

The problem of setting the optimal voting rules is not considered here (as it is not considered in the realities of central banks), rather we focus on the efficiency of voting under the aggregation rules frequently used by central bankers. In this perspective the paper extends the currently used framework of voting analysis by adding an intertemporal dimension and allowing for a stochastic rather than deterministic ‘state of the world’.

The paper is structured as follows. Section 2 presents motivation to our study by analysing the empirical distributions of inflation forecasts produced in central banks and the corresponding

realisations. We find that the forecasts exhibit significant bias caused by the presence of inflation target barriers, potentially resulting from forecast manipulation. Section 3 presents the details of the model. Section 4 contains the main distributional results and Section 5 the inter-temporal simulation results. In Section 6 the assumption of sincere voting is relaxed by introducing strategic behaviour based on a Bayesian learning rule. Conclusions call for the independence of the inflation forecasting units from the Central Bank and more heterogeneity, both in terms of greater diversification of the *MPC* members and a larger variety of forecast information.

2. EMPIRICAL EVIDENCE

We consider the official central banks' inflation forecasts in terms of their distribution, and compare it to the distribution of the realisations, that is, of the observed headline inflation. In practice, inflation forecasts made by central banks might be of two kinds. Forecasts of the first kind are designed to provide information to the decision-makers regarding the most probable path of inflation; their aim being to highlight possible deviations from inflation target so that appropriate action can be taken. Forecasts of the second kind show the most probable paths of inflation development after the *MPC* makes its decision. These forecasts are also of use to the practitioners outside the central bank, helping them in strategic and investment decisions, *etc.* Forecasts of the first kind, called herein early forecasts, are made before the monetary policy decision is undertaken. These forecasts should be unbiased, and institutionally neutral, as their aim is to provide the best possible information to the central bank decision makers.

We analyse data on early forecasts from 10 central banks of countries undertaking inflation targeting: Australia, Canada, Chile, Czech Republic, Korea, New Zealand, Mexico, Norway, Poland and Sweden. These countries are those for which (a) data on forecasts and corresponding realisations are available and (b) it is possible to identify early forecasts which are produced by some sort of research departments and delivered to the board prior to the meetings. On these

grounds we have excluded the UK, as the forecasts are actually made by the committee itself and not by the research department (adding the UK does not change the outcome markedly, these results are available on request). We do, however, include countries in which central banks' target core rather than headline inflation, as the concept of headline inflation is better understood by the recipients of monetary policy and there is usually a negligible difference in long-term forecasts of both. We consider point (or mode) forecasts for 12 and 24 months ahead taken at intervals of approximately 12 months, in order to avoid dependence. The time span, given by the date the forecasts were made, varies between 2000 and 2011, with corresponding observed inflation from periods 12 and 24 months later, ending in 2013.¹ Overall there are 124 pairs of 12-months forecasts and realisations and 99 pairs of 24-months forecasts and realisations. For the sake of comparison between countries, we have scaled the data (that is, forecasts and realisations) by the upper and lower limits of the target bands. We have collected the data on target bands and, if not available, we have assumed the $\pm 1\%$ band around the target. Denoting realisation (headline or core inflation, depending on the bank's targeting policy) by x , and the corresponding forecast by f , we reschedule forecast and realisations as:

$$\tilde{f} = \frac{f - m}{m - low} ; \quad \tilde{x} = \frac{x - m}{m - low} ,$$

where low : lower limit; upp : upper limit and $m = (low + upp) / 2$.

If $|\tilde{f}|$ (or $|\tilde{x}|$) > 1 , the forecast (or realisation) is outside the target bands. If the forecasts are ideal, all $\tilde{f}$'s are equal to the corresponding $\tilde{x}$'s and the distributions of $\tilde{f}$ and $\tilde{x}$ would have been identical. If $\tilde{f}$'s are not perfect, albeit unbiased, forecasts, their distribution would have greater dispersion than that of $\tilde{x}$, with the dispersion increasing with the increase in the degree of inefficiency. In this case the frequency of forecasts and realisations being outside the target

¹ The data, and also the detailed listing of all data sources, are available at <http://pramu.ac.uk>.

band would be approximately equal. Figure 1 shows the distributions and ‘box plots’, illustrating the dispersion (outliers, minimum and maximum excluding the outliers, 0.25th and 0.75th quantile and median) of the distributions of $\tilde{f}$ and $\tilde{x}$ for the 12- and 24 month forecasts.

Figure 1: Distributions of central banks inflation forecasts and realisations with target bands for 10 central banks, 2000-2013. Data are scaled by the inflation target bands

More detailed analysis requires testing the hypotheses that the variances and frequencies of being outside the target zone are identical for forecasts and realizations. Such testing has to take into account that the forecasts and realisations are correlated, so the samples are not independent. In such a case the normal F -test for variance ratio and Z -test for the equality of proportions are not valid. Therefore, we have applied the McNemar test for the marginal homogeneity of the forecasts and realizations (see e.g. Shishkin, 2000, pp. 491-508) and the variant of the Pitman-Morgan test proposed by McCulloch (1987) for testing the equality of variances for paired, possibly dependent, data. McCulloch modification is more robust to the non-normality of data than the original Pitman-Morgan test. Table 1 gives the frequencies of forecasts and realisations being outside the target bands, standard deviations, the McNemar and McCulloch-Pitman-Morgan statistics and, for the sake of completeness, Z -statistics for the equality of proportions and F -statistics for the equality of variances, which are valid only under the (evidently unrealistic) assumption of no correlation between forecasts and realisations.

Figure 1 and Table 1 both show that central banks' forecasts tend to foresee inflation being within the bands much too frequently for the forecasts to be institutionally unbiased, that is,

Table 1: Summary statistics for distributions of central bank inflation forecasts and realisations for 10 countries, scaled by the inflation target bands

	12-months	24-months
Frequencies of forecasts outside target	0.20	0.010
Frequencies of realisations outside target	0.42	0.41
St. deviations of scaled forecasts	0.96	0.48
St. deviations of scaled realisations	1.48	1.44
Z-test for equality of the frequencies above ($N(0,1)$ under the null and sample independence), p -values in the parentheses	3.81 (0.001)	8.00 (0.000)
F -test for the equality of variances of forecasts and realizations ($F(n-1, n-1)$ under the null and sample independence), p -values in parentheses, n is the number of pairs compared	2.37 (0.000)	9.00 (0.000)
McNemar test for marginal homogeneity of the distributions of forecasts and realizations ($\chi^2(1)$ under the null), p -values in the parentheses	20.8 (0.000)	38.1 (0.000)
McCulloch-Pitman-Morgan test for the equality of variances in paired forecasts and realizations; bootstrapped, p -values in the parentheses	5.94 (0.000)	11.1 (0.000)

Source: Computed using central bank *Inflation Reports* and websites of the central banks. Due to the reporting system, in the case of the Czech Republic the 24-month forecasts have been made for shorter periods of 18 or 21 months. We take care to distinguish early forecasts from late forecasts. In cases where this was not clear, we have used forecast made under the assumption of a constant (unchanged) interest rate, or using central interest rates valid prior to meetings deciding on monetary policy.

not influenced by the existence of inflation targets. Overall, for 12 month forecasts, out of 124 forecasts, 25 (that is, about 20%) were pessimistic in the sense that they expected inflation to be outside of the target bands. In reality inflation was outside the target in 52 cases. The 24 month forecasts are even more strongly biased: out of 99 forecasts only one indicated that inflation could be outside the bands. Both the McCulloch-Pitman-Morgan and McNemar tests strongly reject the equality in variances of forecasts and the marginal homogeneity of their distributions.

In other words, while there is no tendency for the forecasters to bias forecasts for the horizons of 1-6 months (results not reported here) it is evident that the majority of the central bankers' inflation forecasts convey a message that 'inflation will be under control after 12, or at most

after 24 months'. The reality shows that this was not often the case. This was not caused by the effect that the inflation forecasts had on setting the targets, as usually the target has been changed very infrequently (in most cases not at all) during the period under research. It suggests that if targets have not been bent towards the forecasts, then the forecasts could be bent towards the targets. In other words, the objective of the forecasters may be to satisfy the expectations of the policy makers rather than delivering unbiased forecast.

However, the above conclusion can be blurred to an extent by the fact that outside forecasts (that is, made by the institutions or individuals which are not dependents of the central banks) might be similarly biased, due to the strong belief in the efficiency of monetary policy, if the reputation of the central bank is strong. Using the terminology introduced by Frenkel, Rülke and Zimmerman (2013), they might either chase after the central banks' forecasts, or intentionally stray away; see also Rülke, Silgoner and Wörz, (2016). Burda *et al.* (2014) failed to find statistically significant support either for such chasing or straying in the case of CPI inflation, however, Pedersen (2015) found evidence of chasing, for short-term forecasts and for the central bank forecasts of Chile. If the chasing explanation were the case, the test results for the forecasts made by the outside forecasters could be similar to those given in Table 1. Consequently the conclusions given above would be unfounded, as it would be difficult to tell the institutional bias from reputational bias. To control for this we have additionally computed test statistics analogous to that given in Table 1 to compare the distributions of bank-produced and externally-produced forecasts.² Data for the externally produced forecast came from the *CESifo World Economic Survey*, which gives up to one-year ahead inflation forecast made by panels of professional forecasters for a group of countries which includes the 10 countries analysed here over the same period (see Wieland, 2014, and, for the description of the

² We are grateful to Petra Geraats and Richhild Moessner for suggesting this to us.

methodology, Stangl, 2007). These data have then been paired with the corresponding banks' forecasts, giving 123 pairs in total.

Table 2: Test statistics comparing distributions of central banks' and independent forecasters' inflation forecasts, scaled by the inflation target bands, 12 months forecast

Frequencies of bank forecasts outside target	0.20
Frequencies of external forecasts outside target	0.29
Z-test for equality of frequencies above ($N(0,1)$ under the null and sample independence), p -values in the parentheses	1.81 (0.035)
F -test for the equality of variances of the banks' and external forecasts ($F(n-1, n-1)$ under the null and sample independence), p -values in the parentheses, n is the number of pairs compared	1.10 (0.297)
McNemar test for marginal homogeneity of the distributions of the banks' and external forecasts ($\chi^2(1)$ under the null), p -values in the parentheses	4.57 (0.033)
McCulloch-Pitman-Morgan test for the equality of variances in paired banks' and external forecasts; bootstrapped, p -values in the parentheses	0.856 (0.187)

Source: For the banks' forecasts, source of the data is as in Table 1. For the external forecasts, forecasts are computed as medians for the *CESifo World Economic Survey* expected inflation rate, available at *Thompson Reuters DataStream* under the heading 'WES: expected inflation rate'.

Results in Table 2 are not fully conclusive. However, they weakly support our conjecture that the distributions of inflation forecasts produced by central banks and those produced outside, are different, and that the banks' forecasts tend to be within the target bands more often than the external forecasts. This is particularly evident by comparing the frequencies of forecasts being outside the target zone (20% for the banks' forecasts opposite 29% for the external forecasts). Also, the McNemar statistic is significant at 5%, confirming non-homogeneity, and the McCulloch-Pitman-Morgan statistic, although non-significant at conventional significance levels, is not high. The Pitman-Morgan type tests usually have a relatively low power, so that rejections of a false null are infrequent (see e.g. Wilcox, 1990). Moreover, the *CESifo* forecasts are in practice for horizons shorter than one year, which likely creates the bias towards the null hypothesis, as the forecast dispersion usually increases with the forecasting horizon. From this we may conclude that the comparison of the banks' forecasts with the external forecasts at a

minimum does not contradict our conjecture of the institutional bias, and, most likely, strengthens it.

In the subsequent sections of the paper we aim to explain this phenomenon by setting up a simulation model which explains the effects of possible institutional influence on voting over monetary policy and, subsequently, on the distribution of inflation. We show that the biased voting can actually increase the volatility of inflation and contribute positively to the observed non-homogeneity of central banks' forecasts and realisations.

3. MODEL

3.1. Assumptions

We consider the voting behaviour of a monetary policy committee with n members over time $t = 1, 2, \dots, T$. In each period the *MPC* votes on monetary policy which affects inflation in time $t+1$. We model simple majority voting, with three possible outcomes: an active anti-inflationary decision, an active pro-inflationary decision and no change. Details of alternative voting schemes, are described in Appendix.

Adopting the Geraats (2009) model for the case of heterogeneous voters (for heterogeneity of the *MPC* voters' preferences, see Faust, 1996), each *MPC* member, indexed by i , $i = 1, \dots, n$, maximises, at time t , the expected value of his/her objective function:

$$W_{i,t} = -\frac{1}{2}\omega_i(\pi_t - \pi^T)^2 - \frac{1}{2}(1 - \omega_i)(y_t - y^T)^2 \quad , \quad (1)$$

where ω_i is the weight given to the inflationary target by individual *MPC* members (assumed to be constant over time), π_t is inflation in time t , y_t is output and π^T , y^T are respectively the inflation and output point targets.

Following Geraats (2009), the economy is described by a simple model:

$$\text{Aggregate demand: } y_t = -r_t + d_t \quad , \quad (2)$$

Phillips curve:
$$\pi_t = \pi_{i,t+1}^e + y_t + \varsigma_{i,t} \quad , \quad (3)$$

where information on the demand curve is identical for all *MPC* members, r_t is the riskless one-period nominal interest rate controlled by the monetary authorities, $\pi_{i,t+1}^e$ is the i^{th} members expected inflation in period t for $t + 1$, d_t is the demand shock (identical for all *MPC* members) and $\varsigma_{i,t}$ is the supply shock, different for the *MPC* members, as they all have different perception of the forthcoming inflation. If it is assumed that (i) there is a lack of economic transparency, (ii) that participants have the ability to predict or deduce supply or demand shocks and (3), $E(d_t) = E(\varsigma_{i,t}) = 0$ for all i and all t , it may be shown that the first-order condition for the i^{th} *MPC* member, after substituting (2) and (3) into (1) and taking expectations, gives:

$$r_{i,t} = \omega_i \pi_{i,t+1}^f + C_i \quad , \quad \text{where } C_i = (1 - \omega_i)(-y^T) \quad , \quad (4)$$

where $r_{i,t}$ is the interest rate fulfilling the first-order condition, that is, maximizing the utility function subject to inflation signals $\pi_{i,t+1}^f$ received by each *MPC* member. Similar results may be obtained using a variety of models and assuming heterogeneity of *MPC* members (see e.g. Woodford, 2003, pp. 246; Besley *et al.*, 2008, Eijffinger and Tesfaselassie, 2006). The inflation signal given to member i at time t , $\pi_{i,t+1}^f$, is a random variable. Although the official forecasts delivered to all *MPC* members are identical, we treat the future inflation signals as heterogeneous but correlated. If the *MPC* members were to rely solely on the official forecast, these forecasts would be perfectly correlated among themselves. We are assuming, however, that each individual forecast is in fact a combination of the official forecast and some other information available (unofficial forecast or personal research) leading to correlated signals.

We consider here the simplest case of the linear correlation across voters as being constant.

Whilst the conditions for this are stringent we focus on this as the most intuitive case.³

The voting rule applied here is:

$$v_{i,t} = \begin{cases} 1 & \text{if } r_{i,t} > s^+ \\ 0 & \text{if } s^- \leq r_{i,t} \leq s^+ \\ -1 & \text{if } r_{i,t} < s^- \end{cases}, \quad (5)$$

where $v_{i,t}$ denotes the decision of the i^{th} MPC member to vote respectively for 1, an anti-inflationary measure, -1, a pro-inflationary measure or, 0, for no change in monetary policy (passive voting). Accordingly, s^- and s^+ stand respectively for the lower and upper voting function thresholds.

As voters are *sincere*, in the sense that their decisions are based (5) alone, the applied voting scheme would be optimal in the Condorcet (1785) sense (for reviews of contemporary description and generalisations see e.g. Young, 1995, Gerling *et al.*, 2005) if (i) the weights are identical for each voter, (ii) the distributions of $\pi_{1,t+1}^f, \pi_{2,t+1}^f, \dots, \pi_{n,t+1}^f$ are independent and (iii) the choice were between two options. In fact none of these assumptions is in general fulfilled here. The sincerity assumption is relaxed further in Section 6. Our model, however, does not allow for truthful communication in the sense of Van Weelden (2008).

3.2 Implementation

In our stylized model, the MPC decision alters the inflation distribution at time $t+1$ by affecting its mean. No other factors alter the distribution of inflation. In other words, if the MPC takes

³ The main conditions for constant correlation are: (i) the unofficial forecasts are uncorrelated with each other and (ii) the weights of the official forecast in combinations with the unofficial are identical for all voters (that is, the members beliefs in the validity of the official forecast are identical). The latter assumption can be relaxed in a straightforward way; however, allowing for a non-constant correlation would muddle the clarity of the main results and would not change the main message here.

no action, the inflation distribution remains unchanged. More generally, the relation between the distribution of inflation at time t and the initial distribution of inflation, π_0 , is:

$$\pi_{t+1} \triangleq \pi_0 - \kappa \sum_{j=1}^t \Psi_j, \quad (6)$$

where $\triangleq$ denotes equality in distribution, Ψ_t is the voting outcome in time t , with values 1, 0 and -1 respectively (hence, 1 represents an anti-inflationary decision and -1 a pro-inflationary) and κ_t measures the efficiency of the monetary policy undertaken in time t for time $t+1$. The voting scheme, resulting in Ψ_t is explained in detail in the Appendix. This specification means that the inflationary distribution is equal to the initial distribution minus the effect of the *MPC*'s interest rate changes. In fact there are, evidently, other factors affecting inflation. However, as we resort to stochastic simulation in our analysis, we may ignore them as long as they do not depend on the monetary policy decisions. The strength of the interest rate effect on inflation, κ , is assumed to be constant in time. More general specifications have been examined, including relating κ to the amount of voting unanimity.⁴ Such generalisations, however, do not affect the general message of the paper and make the model less transparent, so are not presented here.

In the initial model the forecasts are made by the informed forecasters (experts), being subordinated to the *MPC*, e.g. working in the forecasting department of the central bank, who have full knowledge of the inflation distribution at time t . However, they neither know the *MPC* decision prior to it being taken, nor are attempting to double-guess it. This assumption implies that the *MPC* members do not use, in their decision, forecast other than delivered by their 'in house' forecasters. This is a controversial assumption and is worthy of further study. However,

⁴ Making the effect of the interest rate change dependent on the number of members voting in favour of the action increases the degree of *MPC* transparency. As van der Cruysen *et al.* (2010) note, however, this does not necessarily increase performance.

fragmentary and anecdotal evidence suggests that data provided by outsiders', e.g. individual independent forecasts, consensus forecasts, consumers' confidence indices *etc.* are primarily analysed in the forecasting departments of central banks and are rarely used by the *MPC* members on a regular basis.

As in reality at most central banks we consider the *MPC* to request forecasts which are made under the assumption that the next monetary decision will be passive; otherwise it would be required that the forecasters double-guess the policy makers. This is similar in spirit to the Sender-Receiver model by Crawford and Sobel (1982). This implies that the initial forecast signals provided by the experts (which, as it is assumed later, are not necessarily the signals delivered to all *MPC* members), denoted by $\tilde{\pi}_{i,t+1}^f$, are drawn from:

$$\tilde{\pi}_{i,t+1}^f \triangleq \pi_{t+1} \quad .$$

This forecasting scheme is dubbed 'perfect', in the distributional sense, as the forecasters perfectly recognize the distribution of inflation (on the foundations of relations between the forecasters and monetary policy makers see Dow, 2004). This assumption is most conducive to the forecasters. If it is changed in such a way that forecasts are distributionally imperfect, e.g. variance of the distribution of $\tilde{\pi}_{i,t+1}^f$ is either smaller or larger than variance of π_{t+1} , this would create bias which would affect identification of the policy effects.

3.3 First Receiver

One particular *MPC* member, is the first to receive the inflation forecast signal provided by the experts and generated as a realisation of the random variable. Throughout this paper we call him/her the *First Receiver (FR)*. Let us, additionally, assume that the *MPC* members are ordered according to their degree of belief in the forecast, so that $\omega_n > \omega_{n-1} > \dots > \omega_1$ and the most active *MPC* member, numbered n , is the *FR* (although changing this assumption does not affect the

results significantly). Suppose, first, that he/she allows the signal to pass unaltered to all other *MPC* members. If the *FR* actively votes (that is, his/her voting indicator is outside of the boundaries), other members may not necessarily do the same as they have lower weights. This means that there is a possibility that the other committee members votes would go against the *FR*. Additionally, if the *FR* votes passively, other *MPC* members vote passively with probability one only in the case where all forecast signals are perfectly correlated. Here, due to the randomness of the forecast signals, some *MPC* members other than the *FR* may receive information which causes them to vote actively, while the *FR* votes passively. Under these circumstances it is natural to suppose that, as the *FR* genuinely believes in the necessity and efficiency of active voting, his/her objective is to win the vote by affecting the other members' decision. His/her action might cause that the forecast signals delivered to all *MPC* members are:

$$\pi_{i,t+1}^f = \begin{cases} \tilde{\pi}_{i,t+1}^f + \beta v_{n,t} & \text{for } t < n \\ \tilde{\pi}_{i,t+1}^f & \text{for } t = n \end{cases}, \quad (7)$$

where β is the strength of the mean alteration by the *FR*, assumed here to be identical for all i . Hence, if $|v_{n,t}| = 1$, the *FR* alters the mean of the signal delivered to the other *MPC* members in such a way that it inflates the inflation signal by β when he/she wants to vote for an anti-inflationary measure and deflates the inflation signal by β in the opposite case. Otherwise the signal is passed on unaltered.

This type of behaviour has been observed in *MPC*'s, for instance Alan Greenspan would, on occasion, use his power over other members to change their voting behaviour (Blinder, 2007). If neither the thresholds nor weights can be affected, as both of these are characteristics of the individual committee members, the only remaining action for the *FR* is to alter the value of the inflation signal. In practice this is possible when the signal comes from a research division of a

central bank which is subordinated, either formally or informally, to the *FR*. Alternatively, as was discussed in the introduction, the *FR* could affect the interpretation of the signal by more junior members of the committee, either through seniority or persuasive argument. The *FR* alters the forecast signal as:

$$f(\pi_{j,t+1}^f) = \begin{cases} f(\tilde{\pi}_{i,t+1}^f) & \text{if } v_{n,t} = 0 \\ g(\tilde{\pi}_{i,t+1}^f, v_{n,t}) & \text{if } v_{n,t} \neq 0 \end{cases} \quad \text{for } j < n \quad ,$$

Evidently, for the *FR*, $f(\pi_{n,t+1}^f) = f(\tilde{\pi}_{n,t+1}^f)$, as he/she is not going to alter their own signal.

Ways of constructing $g(\pi_{j,t+1}^e, v_{n,t})$ are discussed in the next section of the paper.

4. DECISIONS AND OUTCOMES

4.1 Static Analysis

In order to avoid blurring the results by changes to less relevant parameters the remaining parameters are kept constant. These are:

- (i) The distribution of inflation at time 0 is $\pi_0 \sim N(\bar{\pi}, 1)$;
- (ii) $\omega_i = i / n$ (as voters are ordered from the most sceptical to the most believing, the *FR*).
- (iii) $y^T = 0$, that is the output target is zero. This simplifies the interest rate equation (4), so that it becomes a linear function of the expected inflation;
- (iv) $\kappa = 0.5$ (which corresponds to the magnitude of shifting the mean of inflation distribution by 0.5 in case of an active vote);
- (v) $\beta = 1$.

Figures 2a and 2b examine the effect of the First Receivers actions. They show the simulated distributions of 250,000 replications of the altered forecast signals delivered to the median voter at time $t = 1$ for time $t = 2$. Here $n = 9$ so the median corresponds to the 5th voter, denoted

$\pi_{5,2}^f$. Throughout the paper the inflation target is defined as $\pi^T = 0$ with upper and lower bounds at ± 0.4307 . As the initial distribution of inflation is standard normal, this gives, for $\bar{\pi} = 0$, the probability of hitting the inflation target being equal to 0.333, if the true distribution of inflation is known. The distribution of voting outcomes becomes the Bernoulli distribution only in the case where the probabilities of all three outcomes for all voters are identical. More generally it is a special case of the Poisson binomial distribution (see e.g. Johnson, 2005) and must be calculated numerically. Different voting schemes applied in various central banks have been applied in simulating of banks' decisions. They are explained in the Appendix. Results presented here are for a simple 3-way majority voting system voting, where the decision is taken on the basis of the majority of votes: $\Psi_i = \{-1, 0, 1\}$ with the First receiver having a casting vote in the case of a tie. This scheme is employed in the 'Bank of Sweden', results for other schemes are similar in outcome. We present the results of 3-way voting with a casting vote, as they are intuitively most understandable and easy to interpret.

Figure 2a shows the effect on the altered signal given to the median voter for different means of the initial inflation distribution, that is for the different $\bar{\pi}$'s. In this case the correlation coefficient ρ between $\tilde{\pi}_{1,2}^f, \tilde{\pi}_{2,2}^f, \dots, \tilde{\pi}_{n,2}^f$ is equal to 0.50. In particular, Figure 2a shows the distribution when the mean is within the target zone ($\bar{\pi} = 0$) and when it is outside, that is when $\bar{\pi} = -1, 1$. For $\bar{\pi} = 0$ the distribution of signals is symmetric. The First Receiver imparts no bias on the signal received. Whilst when the mean lies outside of the target zone, with a moderate degree of correlation, the distributions are unimodal and asymmetric (skewed towards zero). As such the effect of the first receiver may be observed. The means of these distributions lie further from the target zone than the means of the underlying inflationary distribution making active policy more likely.

Figure 2b illustrates the effect of the correlation of signals in more detail for the case $\bar{\pi} = 0$ and for two levels of correlation: $\rho = 0.50$ and $\rho = 0.95$. It reveals the bimodal nature of the marginal distributions of forecast signals for cases of high correlation between the signals. The 'saddles' reflect that three normal distributions with different means are combined. That of the unaltered signal and the two distribution when the First Receiver believes action is necessary (either pro- or anti-inflationary). The distance between the true mean and either unaltered mean is equal to β , the size of the first receivers 'push'. The probability of other signals being within this distance increases with the increase in correlation of signals. In the extreme case, where the correlation is unitary (all *MPC* members believe only in the official forecast), the conditional probability of $\Pr(\tilde{\pi}_{n,t+1}^e - \pi_{i,t+1}^e < \beta | I_{n,t}^{(1)} = 1) = 0$ for all $i < n$.⁵ As such correlation makes the effect of the first receivers signal alteration broader across more of the members.

Fig 2: Distribution of the altered forecast signals delivered to the median voter at time $t = 1$ for time $t = 2$.
Results generated from 250,000 repetitions

⁵ This result shed a new light on the problem of correlated votes in the heterogeneous case (see Kaniovski, 2010). It shows that in the case of strong correlation between voters and signal alteration, extreme behaviour is likely to appear, as the signals delivered to the median voter are unlikely to be of a moderate magnitude. This finding might have further, interesting implication of a more general nature (sociological or psychological), however, this is beyond the scope of this paper.

In the remainder of this section we discuss selected distributions of voting results and decision for the model defined above. Figures 3a-3d present the simulated distributions of $I_t^{(k)}$ $k=\{-1,0,1\}$, when $\bar{\pi}=0$, both with ($\beta=1$) and without signal alteration ($\beta=0$) and for two different signal correlations: $\rho=0.5$ and $\rho=0.95$. As expected, the results in Figures 3 show the symmetry of the active voting results, as the probabilities of voting -1 or 1 are practically identical. In the case of a moderate correlation between forecast signals and no First Receiver intervention, the distribution of passive votes $I_t^{(0)}$ is close to being symmetric and unimodal.

Figure 3: Distributions of votes of MPC members for each action ($k=1, -1, 0$), when the mean of the inflation distribution is in the middle of the target zone ($\bar{\pi}=0$, both without ($\beta=0$) and with signal alteration ($\beta=1$) and for two different signal correlations: $r=0.5$ and $r=0.95$. Results calculated from 250,000 repetitions.

Figure 3a: $\rho=0.5, \beta=0$

Figure 3b: $\rho=0.5, \beta=1$

Figure 3c: $\rho=0.95, \beta=0$

Figure 3d: $\rho=0.95, \beta=1$

This reflects the centre distribution in Figure 2a, where the majority of signals in this case lie within the inflation target and so entail passive voting. The *FR*'s intervention flattens the distributions; fewer individuals vote for passive policies and three way split outcomes become less frequent as members are 'persuaded' to change their decisions by receiving altered signals.

Increased correlation between signals causes the distribution to become *U*-shaped. Probabilities of split votes are again visibly smaller. More weight is given to zero or high numbers of votes for particular actions. The decisions are determined more by the weights (preferences) of the particular *MPC* members rather than by the forecast signals. The combination of high correlation and signal alteration makes most decisions near unanimous.

The model presented above has a relatively simple specification, however, similar results may be obtained with more general variations. In particular, we have examined models where:

- The decision barriers in (5) are not constant (values dependent on time and on previous voters' behaviour).
- In (6) the strength of monetary decisions varies according to the degree of unanimity of the Board.
- The distribution of inflation is skewed normal rather than normal.
- Different voting schemes other than the three-way voting.
- The deviation of the output gap from the target is not zero.
- A nonstationary (random walk) inflation process.
- The *FR* is not the most active *MPC* member, that is his/her ω_i in (4) is not the highest.

In all cases these generalisations do not change the results in a significant way. If the assumptions are generalised (which, in the context of a simulation model, is technically straightforward), the model becomes more realistic, but the causal relations less visible.

4.2 Dynamic analysis

This section explains the intertemporal aspect of the model and focuses on the static and dynamic characteristics of the inflation distribution and the efficiency of monetary policy over a longer time period. Recall the only factors affecting the distribution of inflation at time $t+1$ is

the decision of the *MPC* and its strength, see (6). If there were no voting the inflation distribution π_t is (for $\bar{\pi} = 0$) a standard normal. However, any active *MPC* decision affects the distribution, as is evident from (6) and from the distributional results shown above.

Figures 4 show the standard deviation of inflation and a measure of the effectiveness of monetary policy at hitting the inflationary target, over 25 consecutive periods. The settings of the experiments are as described in Section 2 points (i)-(v), whilst the initial inflation is on target, $\bar{\pi} = 0$, and the correlation is $\rho = 0.5$. There are 25,000 replications of each run. Policy efficiency is measured by the ratio of the *ideal undisturbed inflation distribution* π^{IU} (that is, the hypothetical inflation distribution not subject to *MPC* decisions and with a mean in the middle of the inflation target) being within the target relative to that of the inflation distribution subject to *MPC* actions being within the target at time t . This ratio, called the *ratio of deviations from target* and denoted by *RDT*, is computed as:

$$RDT_t = 1 - \frac{\Pr(\pi^- < \pi_t < \pi^+)}{\Pr(\pi^- < \pi^{IU} < \pi^+)} ,$$

where π^- and π^+ are respectively the lower and upper limit of the inflation target. $\Pr(\pi^- < \pi_t < \pi^+)$ is approximated by running 10,000 replications of voting for $t = 1, 2, \dots, 25$. Other settings are as given in Section 3 above, with the correlation coefficients between forecast signals, ρ , being equal to 0.5. Under these settings, for $\pi_0 \sim N(0,1)$ and $\pi^+ = -\pi^- = 0.4307$:

$$\Pr(\pi^- < \pi^{IU} < \pi^+) = \Pr(\pi^- < \pi_0 < \pi^+) = 0.333$$

If $RDT=0$, it indicates that the efficiency (in terms of probabilities of hitting the inflation target) is equal to that of π^{IU} , i.e. *MPC* actions do not on average improve the probability of hitting the inflation target. If $RDT < 0$, the target hitting efficiency is better than that of the π^{IU} , and if

$RDT > 0$, it is worse. It is convenient to give the RDT measure in percentages, which show to what extent the current inflation distribution is worse (or better) than the ideal unaffected case.

Figure 4a: Standard deviation of inflation distribution under both the altered and unaltered signals over time. Results calculated from 250,000 repetitions with $\bar{\pi} = 0$ and $\rho = 0.5$.

Figure 4b: Ratio of deviations from inflation target over time under both the altered and unaltered signals. Results calculated from 250,000 repetitions with $\bar{\pi} = 0$ and $\rho = 0.5$.

Active monetary policy decisions undertaken unnecessarily, as in this case where $\bar{\pi} = 0$, will result in a decrease in the inflation targeting efficiency in the sense that the probability of hitting the inflation target is diminished. This is seen in Figure 4b, in both cases the RDT is markedly above one, indicating a loss in efficiency in relation to the case where no decision is made. However, in the case where there is signal alteration the RDT is markedly higher. This inefficiency comes from a higher standard deviation of inflation. Recall that the standard deviation of the inflation distribution under no decisions is 1. Figure 4a shows that in both voting cases, although notably more for the altered signal, the inflation dispersion is greater than the initial unitary dispersion, i.e. voting makes inflation variation greater leading to less efficiency.

Further analysis suggests there may be some degree of persistence explained by time delays in taking the inflation process back towards the inflation target zone after a disturbance. As the presence and degree of this depends on the initial draw from π_0 , a more sophisticated simulation is needed in order to assess whether such persistence is independent from initial

values. Using the same settings as above, 5,000 runs of the dynamic experiment are performed, each starting from with a different draw from π_0 . In each run $t = 1, 2, \dots, 50$ and, for each t , there are 5,000 replications, giving a total of 25,000,000 replications. For the resulting series of means of inflation distributions, $\pi_1, \pi_2, \dots, \pi_{50}$, autocorrelation coefficients of orders up to 8 are computed and tested for one-sided (positive) significance at the 5% level. If there is no autocorrelation, the empirical frequency of rejections in a sample of 5,000 autocorrelation coefficients should be around 5%. Figure 5 presents the frequencies of such rejections for cases where there is no signal alteration ($\beta = 0$) and with signal alteration ($\beta = 1$).

It is evident that *MPC* voting substantially contributes to inflationary persistence by creating positive autocorrelation up to an order of at least 3. Moreover, voting alteration visibly increases such persistence at early lags. As a result active monetary policy set through voting can be seen to add persistence to inflation and may partially explain the fat tailed distributions seen empirically. This finding is robust across different values of ρ , the within period correlation of signals received by committee members.

Figure 5: Frequencies of positive autocorrelation of the inflation distribution measured at 5% level of significance. Statistics calculated from 2,500,000 data points with and without signal alteration.

The above experiments have been performed under the assumption that voting was unnecessary, as inflation, in terms of its distribution, was already on target $\bar{\pi} = \pi^T = 0$. It is, however, important to know to what extent signal alteration by the *FR* might be effective if

inflation is initially off target. Clearly, if it differs from the target in the sense that $\bar{\pi} \neq 0$ and $\Pr(\pi^- < \pi_0 < \pi^+) < 0.333$, then active policy may be beneficial and intervention of the *FR* may lead to an increase in the probability of hitting the target. This potential benefit, however, may be offset by an increase in volatility and persistence as seen above. Figures 6a-6c present the simulated offset effect, measured by a comparison of *RDT* with and without signal alteration over, respectively, 1, 2 and 3 periods, for initial inflation $-1 \leq \bar{\pi} \leq 1$. Recall that, for a given $\bar{\pi}$, the lower the *RDT* is, the more efficient is the monetary policy. The distance between the upper and lower points for which the *RDT*'s of policy with and without signal alteration coincide define the *non-advantage band*. Within this band it is counterproductive to alter forecast signals, as the distance between the mean of actual inflation and the target is not sufficiently large. If the *FR* alters the signal the action is likely to overshoot the target and the alteration is not beneficial. In all cases, however there exist initial inflation disturbances

Figure 6: Ratios of deviations from inflation target (offset effect) with and without signal alteration for initial values of the inflation distribution $\bar{\pi}$ varying between -1 and 1 . Figures show distributions for 1, 2 and 3 steps policy. Results averaged for 250,000 repetitions with $\beta = 0$ (unaltered signal) and $\beta = 1$ (altered signal).

Figure 6a: 1 periods policy

Figure 6b: 2 periods policy

Figure 6c: 3 periods policy

which are sufficiently large to make the signal alteration of the First Receiver beneficial to the economy. As the policy horizon increases, *FR* intervention becomes less likely to help. Both *RDT* curves flatten as the committee has multiple chances to act to return inflation to the target and as a result the non-advantage band increases in width. For longer horizons it is only under very large deviations that the first receiver's actions reduce the *RDT*. With relatively small deviations, it does not pay to intervene in the forecast signals.

5. LEARNING

In previous sections we have assumed that all voters behave sincerely, that is they base their votes solely on the information received, as incorporated in their decision functions. We have assumed so far that voters other than the *FR* do not actively oppose or adapt their behaviour to possible *FR*'s manipulation and that they are fully convinced by the forecast signals received. In reality, however, committee members may have incentives to modify their behaviour according to their beliefs regarding the sincerity of the *FR* actions. In this section we consider a mechanism by which they could do this. Individuals may learn from previous 'suspicious' behaviour of the *FR*. They may treat inflation forecasts from the *FR* with a degree of scepticism, changing the degree to which they respond to these signals. In the context of *MPC*'s Lim and McNelis (2004) consider how the *ECB* may learn the laws of motion of inflation under different targets.

We model learning through the naive Bayesian classifier (see e.g. Mitchell, 1997, Domingos and Pazzani, 1997 and, for further development, Chapelle *et al.*, 2006; for possible alternative techniques applicable here e.g. Schorfheide, 2004, and Honkapohja and Mitra, 2006). It is assumed that the *MPC* members other than the *FR* might suspect the *FR* of signal alteration and, if this suspicion is strong enough, they may attempt to offset this possible signal alteration by shifting the mean of the forecast distribution in the opposite direction.

Recalling that the *FR* is the n^{th} *MPC* member, $\Pr(v_{n,t} \neq 0)$ is defined as the probability that at time t the *FR* will conduct signal alteration (see Section 2). Similarly $\Pr(v_{i,t} \neq 0 | v_{n,t} \neq 0)$, $\Pr(v_{i,t} \neq 0 | v_{n,t} = 0)$ denote the probabilities, respectively with and without signal alteration, that the i^{th} *MPC* member ($i < n$) after receiving information should vote actively *i.e.* $v_{i,t} \neq 0$. The committee member can classify the state of the world in which it was conducive for the *FR* to alter the signal ($v_{n,t} \neq 0$) or not ($v_{n,t} = 0$) by selecting from:

$$d_{n,t}^{\text{Bayes}} = \arg \max_{\{v_{n,t} \neq 0, v_{n,t} = 0\}} \{ \Pr(v_{n,t} \neq 0) \Pr(v_{i,t} \neq 0 | v_{n,t} \neq 0), \Pr(v_{n,t} = 0) \Pr(v_{i,t} \neq 0 | v_{n,t} = 0) \} , \quad (8)$$

that is, choosing such arguments from $v_{n,t} = 0$, $v_{n,t} \neq 0$ which maximizes the posterior probability of voting actively. If $d_{n,t}^{\text{Bayes}} = \{v_{n,t} = 0\}$ he/she decides that no voting alteration took place and votes according to the signal received. If, however, $d_{n,t}^{\text{Bayes}} = \{v_{n,t} \neq 0\}$, the n^{th} *MPC* member decides that the alteration took place they revise the signal accordingly.

In order to make (8) operational, it is assumed here that the *MPC* members have information regarding earlier signal alterations and their magnitude, *i.e.* they know β in (7). These values are constant over time and so we assume the members may estimate them through observing previous inflation outcomes and signals. Hence $\Pr(v_{n,t} \neq 0)$ is estimated as:

$$\hat{\Pr}(v_{n,t} \neq 0) = \frac{1}{t-1} \sum_{j=i}^{t-1} (v_{n,j} \neq 0) \text{ and } \hat{\Pr}(v_{n,t} = 0) = 1 - \hat{\Pr}(v_{n,t} \neq 0) .$$

With Bayesian learning, (7) is replaced by:

$$\begin{aligned} \tilde{\pi}_{i,t+1}^f &= \tilde{\pi}_{i,t+1}^f + \beta v_{n,t} , \text{ and:} \\ \pi_{i,t+1}^f &= \begin{cases} \tilde{\pi}_{i,t+1}^f & \text{if } d_{n,t}^{Bayes} = \{v_{n,t} = 0\} \\ \tilde{\pi}_{i,t+1}^f - \beta v_{n,t} & \text{if } d_{n,t}^{Bayes} = \{v_{n,t} \neq 0\} \end{cases} . \end{aligned} \quad (9)$$

Under (9) it is possible for the i^{th} MPC member to make a mistake by wrongly correcting previous unaltered forecast as finding that $d_{n,t}^{Bayes} = \{v_{n,t} \neq 0\}$ does not necessarily mean that signal alteration really took place.

The effect of learning on the probability of reaching the inflation targets is illustrated in Figure 7. It shows the ratios of average *RDT*'s, where the numerator is the average *RDT* of the model without learning and the denominator is an analogous average *RDT*'s for a model with learning. As the *RDT* shows losses in efficiency due to signal alterations, the ratio can be interpreted as the average gain of implementing a voting defence mechanism relative to the case where such a mechanism is absent. All model settings are as above with $\bar{\pi} = \pi^T = 0$ for different ρ (correlation between inflation signals delivered to the particular MPC members) changing by 0.05 from 0.15 to 0.95 (17 cases) and time horizons, changing by 5 from 5 to 65 (13 cases). The number of replications for each combination of time horizon and r is equal to 25,000 in all cases.⁶

⁶ Costs of these computations are significant and in practice require a high-powered (parallel) computer.

Figure 7: Ratio of deviations from inflation target for different correlations and different learning time horizons. Positive values indicate improvements in performance. Results calculated from 25,000 repetitions with initial and target inflations set to zero ($\bar{\pi} = \pi^T = 0$) and different correlations between voters ρ .

The RDT ratios in Figure 7 are always greater than one, which illustrates that learning provides a strong countermeasure to signal alteration despite the fact that individual decisions can sometimes be wrong (that is, voters might think that the FR has altered the signal, when in fact such action has not taken place). Dependence on correlation and time is evident here. Bayesian learning is more efficient with longer time horizons (more time to learn) and is also more efficient when inflation signals are more heterogeneous. Clearly the time dependence is nonlinear here, with gains rising more quickly with the increase in time horizons for shorter rather than longer periods of time.

6. CONCLUSIONS

The findings of this paper explain the observed bias of central banks' inflation forecasts towards targets. The paper provides empirical evidence of anti-herding behaviour of the *MPC* forecasters (in relation to independent forecasters), confirming indirectly the earlier findings of Fritsche *et. al* (2015) and Rülke, Silgoner and Wörz (2016). In this spirit the paper explains behaviour through the organisational structure of a hypothetical monetary policy council. It

finds that if a particular member of a *MPC* is in position to alter inflation forecast signals delivered to the rest of the committee, it may negatively affect the ability of the committee to meet an inflationary target. This is the case even if alteration is well-motivated, that it, aimed at achieving an inflationary target. Negative effects of signal alteration are evident when the inflation distribution is in fact on (or close to) the target in terms of its mean. In this case any active voting can be damaging so that, if signal alteration increases the possibility of such voting, it worsens the efficiency of the monetary policy. The excessive decision activity increases the volatility of inflation and, perversely, decreases the chances of hitting the target zone. This confirms hypothesis [1] formulated in Section 1. It also creates persistence in inflation, which additionally negatively affects the monetary policy effectiveness and is one of the sources of non-normality of the distribution of inflation and autocorrelation which, in turn, confirms hypothesis [2]. Only if inflation is a long way from the target can alteration of signals improve the efficiency of the *MPC*. If members of the Monetary Policy Board can learn about such alterations, they may counteract the changes effectively even if occasionally they misjudge the alteration.

In practice signal alterations can be made either by the Governor of the Bank, the head of its forecasting (research) division, or a person who has particularly strong institutional or psychological influence on the forecasters. The simplest practical solution here would be to separate the process of forecasting from the Bank and put it in the hands of an independent organisation such as a university or a consulting firm. As heterogeneity of forecasting signals plays an important, positive, role in increasing efficiency, it is relevant to diversify such signals and gain forecast information from as many independent sources as feasible. Presumably a better, albeit more costly, way out of the problem, could be to create a designated separate unit (panel) of professional forecasters, fully independent from the Bank in terms of accountability

and influences. As the quality of forecasts positively affects the *MPC*'s efficiency, it is important that such a panel consists of the best available professionals or research units.

Under the alternative interpretation of the model, as suggested in Section 1, where the First receiver affects the perception rather than signals themselves, conclusions are similar. Even if only one forecast is delivered to the monetary policy board, its quality or interpretation should not be subject of discussion, as it would result in correlation of perceptions and strengthening the power of the First Receiver in relation to other members of the *MPC*.

Under both interpretations, it is clear that monetary policy decisions can affect the distribution of inflation even if there is no manipulation of the forecast signals. If the distribution of inflation would have been normal in the absence of any efficient monetary policy, it becomes non-normal when such policy is efficient in bringing inflation close to target. This is evidently not the only cause of the non-normality of the distribution of inflation, but it is likely to be a significant one in inflation-targeting economies.

APPENDIX: VOTING SCHEMES

As the voting schemes, are static, we can re-write (5), representing the voting intention of the i^{th} MPC member, $1, \dots, n$, by dropping the subscript t , that is:

$$v_i = \begin{cases} 1 & \text{if } r_i > s^+ \\ 0 & \text{if } s^- \leq r_i \leq s^+ \\ -1 & \text{if } r_i < s^- \end{cases} .$$

Denote the sums of votes for outcome $k = \{-1, 0, 1\}$ as $\Gamma^{(k)} = \{\# i \in \{1, \dots, n\} \mid v_i = k\}$. Hence, $\Gamma^{(k)}$ takes values from 0 (no vote for outcome k) to n (unanimous voting for outcome k). The MPC voting results in the decision $\Psi = -1, 0$, or 1 , where -1 stands for a pro-inflationary measure (e.g. a reduction in interest rate), 1 for an anti-inflationary measure (e.g. an increase in interest rate) and 0 in maintaining the status quo. In the main body of the paper Ψ is denoted as Ψ_t .

Stylized voting mechanisms of particular central banks resulting in a decision Ψ are:

1. ‘Federal Reserve Board’ voting: according to the ‘Fed’ scheme one member of MPC the (the Chairman) proposes a motion, which is either supported by the majority (including the Chairman), or not. If the Chairman proposes to maintain the status quo ($\Psi = 0$) it is uncontested and, in the case of a tie in voting, $\Psi = 0$. The voting decision is then:

$$\Psi = v_c \times \mathbf{1}_{\Gamma^{(v_c)} > n/2} ,$$

where $\mathbf{1}_{A>B}$ is an indicator function and v_c , indicates the voting intension of the Chairman.

2. ‘Bank of England’ voting: The decision is equal to the median vote. In case of a tie and when the number of voters n is even, there is no change. Hence:

$$\Psi = \sum_{k \in \{-1, 0, 1\}} k \times \mathbf{1}_{\Gamma^{(v_c)} > n/2} .$$

3. ‘Bank of Sweden’ (BoS) voting. This is a 3-way majority voting system, where the decision is taken on the basis of the majority of votes -1, 0 and 1, with the Chairman having a casting vote in the case of a tie. If there is a tie and the Chairman is in the minority; it is assumed that he/she votes in favour of the group to which their preferences are closer, in terms of distance. Such a voting scheme may be described as:

$$\Psi = k \times \mathbb{1}_{\text{card } k_{\max}=1} + v_c \times \mathbb{1}_{v_c \in k_{\max}} \times \mathbb{1}_{\text{card } k_{\max}>1} + \text{sgn}\left(r_c - \frac{(s^+ - s^-)}{2}\right) \times \mathbb{1}_{0 \notin k_{\max}; v_c \notin k_{\max}; \text{card } k_{\max}=2} \quad ,$$

where $k_{\max} = \{k \in \{-1, 0, 1\} \mid \Gamma^{(k)} \geq \Gamma^{(\ell)}, \ell \in \{-1, 0, 1\}\}$ and $\text{card } k_{\max}$ denotes the cardinal number for $k_{\max}$. That is, $k_{\max}$ indicates the voting outcome which attracts most votes. It contains one element in case of a unique majority, and two elements in case of a tie.

4. ‘Bank of Canada’ and ‘Bank of Australia’ voting. This is 3-way majority voting, but without a casting vote, with $\Psi = 0$ in case of tie, that is:

$$\Psi = k \times \mathbb{1}_{k \in k_{\max}} \times \mathbb{1}_{\text{card } k_{\max}=1} \quad .$$

5. ‘Bank of Poland’ voting. This is an absolute majority voting scheme such that the voters first vote for the $\Psi = 1$ motion, with the Chairman having the casting vote. If there is no absolute majority (or if, in case of a tie, the motion is not supported by the Chairman), there is another vote for the $\Psi = -1$ motion. If this vote is not decisive, again considering the casting vote of the Chairman, the result is $\Psi = 0$. Assuming that there is no change in voting intensions between two rounds of voting, the scheme is:

$$\Psi = \mathbb{1}_{\Gamma^{(1)} > n/2} + \mathbb{1}_{\Gamma^{(1)} = n/2} \times \mathbb{1}_{v_c=1} - \left(\mathbb{1}_{\Gamma^{(-1)} > n/2} + \mathbb{1}_{\Gamma^{(-1)} = n/2} \times \mathbb{1}_{v_c=-1} \right) \quad .$$

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