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Central Banks' Voting Record and Future Policy

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PRELIMINARY. COMMENTS WELCOME.

Abstract

We assess whether the voting record of the central bank board members helps predict future monetary policy to those who have access to this record prior to the next monetary policy meeting. First, we fully specify a model of central bank committee decision making process and simulate decisions taken by the model committee. The model assumes endogenous nature of status-quo decision in central bank decision making process, uncertainty and time dependence in optimal monetary policy as well as private information on the part of individual committee members. The three different versions of model are estimated with simulated data: 1) democratic, 2) consensual and 3) opportunistic. In principle, these versions differ in the extent how chairman influences the voting of other board members with the chairman allowing democratically to express the opinion of other board members in 1), having a dominant position to force consensus in 2) and voting opportunistically according to the majority of other board members in 3). The model shows that their voting pattern contains predictive power about future monetary policy provided that the signals about optimal policy rate are noisy and sufficient independence in voting across board members exist, which is in line with the democratic version of the model. Next, the model predictions are tested on real data. For this reason, data on five countries (the Czech Republic, Hungary, Poland, Sweden, the United Kingdom and the United States) that release their voting records are collected. It is found that in all countries the voting records indeed improve monetary policy predictability making a case for the democratic version of the model in these central banks. The empirical results are robust to controlling for a measure of disagreement in the committee as well as different sample periods. Finally, empirical analysis shows that financial markets would benefit from adding voting record to their information set.

JEL Classification: C78, D78, E52, E58.

Keywords: monetary policy, voting record, transparency, collective decision-making.

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1 Introduction

The monetary policy transparency has increased dramatically over the course of last two decades (Geraats, 2009, Posen, 2003). Nowadays, central banks¹ typically communicate effectively with the public and explain their policies in a great detail. Every monetary policy decision is accompanied by the minutes or press releases that outline the arguments that central bankers expressed during the monetary policy meeting. Some central banks release the attributed voting records typically together with minutes. In this paper we aim to examine whether the voting records convey new information in addition to all other information already incorporated into financial market expectations. Since central bank boards decide based on majority vote, we are able to calculate the indicator called *skew* defined as the difference between the average policy rate voted by individual board members and the policy rate that is the outcome of the majority vote. Our theoretical as well as empirical model essentially test whether it is more likely that there will be a rate hike in the future, when there are some minority votes for higher rates than the decided-on rate and *vice versa*. While some previous research has examined the information content of voting record in the case of U.K. (Gerlach-Kristen, 2004), many other central banks' voting records were not examined empirically yet. Similarly, there is also a lack of theoretical studies examining whether voting results are useful for understanding of future monetary policy.

On the theoretical side we fully specify a model of central bank committee decision making process, simulate decisions taken by the model committee and assess predictive power of voting pattern for future monetary policy. Basic version of our model is similar to the model of Riboni and Ruge-Murcia (2008a) in acknowledging endogenous nature of status-quo decision in central bank decision making process. Besides endogenous status-quo our model also incorporates uncertainty and time dependence in optimal monetary policy as well as private information on the part of individual committee members, in a way similar to Gerlach-Kristen (2008). Our approach, specifying the model and then proceeding using computer simulations, is also similar to the article just mentioned. We use several alternative models of monetary policy committee decision making that differ (among other things) in degree of informational influence among its members and that are related to the models already found in relevant literature (Gerlach-Kristen 2008, Riboni and Ruge-Murcia 2010 and Weber 2008). Our theoretical model shows that the voting record contains important information about future monetary policy provided that the signals about optimal policy rate are noisy and large degree of information independence among the committee members exist. Even if both of those aforementioned conditions hold the

¹ Fry et al. (2000) reports that approximately 90% central banks around the world make decisions in committees.

predictive power of voting record can be overridden by high volatility of economic environment or by enough noise in the committee members' information with larger committee size counteracting both of those effects.

In the empirical part, this paper examines the impact of releasing of voting results in five inflation targeting countries – the Czech Republic, Hungary, Poland, Sweden and U.K. – and the U.S. on the monetary policy predictability. In consequence, our research gives greater international perspective in comparison to previously published studies and it is able to draw conclusions that are not country-specific.

Our empirical results confirm the theoretical conclusions. The voting record improves predictability of future monetary policy changes in all sample countries in comparison to information set utilized in financial market expectations prior to the voting record announcement. This result is robust to measure of disagreement in the committee as well as to the different sample periods. It is interesting to note that our dataset provides two 'natural experiment' setups, where we can quantify the effect of publicly unavailable voting results (for the case of Poland and the U.S.) and the effect of publicly unavailable names of voting members (for the Czech case). In both cases, the information is released with a too long time lag to improve information set available to financial markets prior to the next monetary policy decision. Also in these cases, the voting record helps predict future policy. This finding implies that committee members tend to put the same effort into forming their views no matter whether their voting is published soon after the meeting or after a longer period of time. It also implies that releasing the names themselves is less important than releasing the voting outcome as such.

The paper is organized as follows. Section 2 contains the related literature. Section 3 introduces a theoretical model of central bank board decision making. Section 4 presents the institutional background on monetary policy decision-making in our sample countries. Empirical methodology is discussed in section 5. Section 6 gives the results. Section 7 offers concluding remarks. The appendix with details of the theoretical model, details of institutional background on monetary policy decision-making and data description follows.

2 Related Literature

On the most general level the question of whether voting records of central bank boards and monetary policy committees (MPCs) reveal information about future changes in monetary policy

is related to the literature on central bank communication and central bank transparency surveyed by Blinder et al. (2008) and Geraats (2002, 2009) respectively. The general conclusion of both strands of the literature is that the way central banks communicate to the public and the degree of their transparency matters for monetary policy. Most of the theoretical and empirical studies also indicate the benefits of more open and more transparent central bank behaviour. However, not all the studies reach unequivocal conclusions. For example, the model in Morris and Shin (2002) leaves open the possibility that more information provided by a central bank is welfare reducing, while Meade and Stasavage (2008) show that the Federal Reserve's decision to release full transcripts of Federal Open Market Committee (FOMC) meetings decreased the incentives of its participants to voice dissenting opinions. Winkler (2000) draws similar conclusions and puts forward a conceptual framework to distinguish different aspects of transparency.

However, the empirical literature investigating the predictive power of voting records about future changes of monetary policy is rather scant. This is mainly due to the fact that the practice of publishing the voting records of board members has been adopted only recently and several central banks make the voting records public only in transcripts of their monetary policy meetings, published with a several-year lag.

For the MPC of the Bank of England, Gerlach-Kristen (2004) shows that for the period 1997–2002 the difference between the average voted-for and actually implemented policy rate helps to predict changes in the policy rate in the future, a conclusion robust to the inclusion of different measures of market expectations. In a similar spirit and using the same measure of dissent in the MPC, Fujiki (2005) reaches a similar conclusion for the Bank of Japan. For the Riksbank, Andersson, Dillen and Sellin (2006) reach a similar conclusion.

The empirical literature trying to estimate the reaction functions of individual bank board members using information about their voting behaviour is closely related. In this case information about the votes of individual members is used to predict their preferred policy rate given the state of the economy and hence to better forecast future monetary policy decisions. For the Federal Reserve, Chappell, McGregor and Vermilyea (2005) estimate the individual reaction functions of FOMC members. For the Bank of England MPC, Bhattacharjee and Holly (2006, 2010), Brooks, Harris and Spencer (2008), Besley, Meads and Surico (2008) and Riboni and Ruge-Murcia (2008b) conduct a similar exercise.

The general conclusion emerging from these studies is that there is often significant evidence of heterogeneity among the bank board members. In combination with the assumption that monetary policy is better conducted in an environment with no information asymmetry between the central bank and the markets, the publication of voting records revealing the heterogeneity of the bank board members is desirable.

From the theoretical side, the question whether the voting records of bank board members can help to predict future monetary policy decisions is virtually untouched. One of the reasons is the difficulty of modelling committee decision-making with members who hold possibly different beliefs and objectives in the uncertain monetary environment. A further difficulty is presented by the dynamic nature of central bank decision-making, as a policy rate adopted today becomes the status-quo policy for the next meeting.

Furthermore, it is not entirely clear what is the appropriate assumption to be made about the way bank boards reach decisions. While in reality the chairman usually holds most of the proposal power, empirical evidence in Riboni and Ruge-Murcia (2010) suggests that what they call a consensus model better captures the real-world features.

Riboni and Ruge-Murcia (2008a) try to model central bank decision-making taking into account its dynamic nature. They show that even in periods in which policy-makers' preferences do not differ; they may fail to reach a consensus and change the policy from the status quo, due to the possibility of future disagreement. However, it is not clear whether their model can support the information content of voting behaviour, despite the fact that it produces persistence and strong autocorrelation of policy rates.

Disregarding the dynamic nature of central bank policy-making, Gerlach-Kristen (2008) investigates a role of the MPC chairman in committee decision-making in a model that generates real-world-like dissenting frequencies. The possibility of dissent arising is due to the fact that individual policy-makers receive private information about the unobserved optimal interest rate. Differences in private information sets among the MPC members then give rise to different votes by the time the policy decision is made.

The model in Weber (2008) then supports the basic intuition that the publication of voting records reveals the bank board's opinion heterogeneity and thus provides more information to

the financial markets than the publication of the final decision only. Better informed financial markets are then able to better predict the central bank's future behaviour, providing a rationale for the publication of voting records.

As regards previous relevant CNB research, Kotlán and Navrátil (2005) study the predictability of Czech monetary policy, examining to what extent the policy decisions were priced-in by the financial markets. Nevertheless, they do not focus on the impact of releasing the voting record. Bulíř et al. (2007) assess the content of inflation reports in six inflation targeting countries and evaluate the consistency of central bank communication.

3 A Model of Central Bank Board Decision Making

In this section we introduce a theoretical model of central bank board decision making process and investigate whether voting pattern can predict future changes in the interest rate. General objective is to fully specify the model, simulate path of decisions recording preferences of individual committee members and use those in a regression similar to the one from empirical part.

3.1 Model setup

The model is set in an infinite horizon with discrete periods denoted by $t = 0, 1, \dots$ in each of which monetary policy committee or board takes a decision about policy instrument with a policy adopted at t denoted by p_t . Although we call p_t interest rate it can stand for any standard monetary policy instrument.

There is N (N even) 'normal' board members P (he) and one proposer or chairman C (she). Therefore, the committee size is odd. In each period t decision making is done by a standard majority rule with two alternatives pitched against each other. First alternative is current status-quo policy x_t that is equal to the policy adopted at $t - 1$, i.e. $x_t = p_{t-1}$. Second alternative is policy proposed by chairman which we denote by y_t . Alternative which obtains majority of votes then becomes new policy p_t . For mathematical convenience we assume that C who cannot propose anything better than x_t indeed proposes x_t (instead of proposing policy that would be rejected for sure).

The committee is trying to set policy p_t so as to match uncertain 'state of the world' denoted by i_t^* where for inflation targeting central banks i_t^* can be interpreted as an interest rate that is

compatible with achieving inflation target over time. We assume that per period utility function of all committee members is quadratic around i_t^* and is given by $-(p_t - i_t^*)^2$. Note that even though board members share equal goal embedded in a common utility function their behaviour can (and will) depend on their private information which is not necessarily homogenous.

We assume that the unobserved state of the world follows $AR(1)$ process given by $i_t^* = \rho i_{t-1}^* + u_t$ where $\rho \in (0, 1)$ with u_t being *i.i.d.* shock with $N(0, \sigma_u^2)$ distribution. That is, the optimal monetary policy changes over time with current optimal interest rate influenced by previous period optimal interest rate and eventually converging to some long run value compatible with stable state of an economy. With our interpretation of i_t^* as an optimal interest rate it might seem unrealistic to assume that it can attain negative values, but the whole model and all the results are invariant to adding a constant to the optimal interest rate.

To generate non-homogeneous votes among committee members we assume that each member j has an imperfect signal i_t^j about i_t^* given by $i_t^j = i_t^* + v_t^j$ where the noise v_t^j is *i.i.d.* with $N(0, \sigma_j^2)$ distribution. The assumption of non-homogenous views of the individual committee members about the state of the economy is perfectly in line with the observed practice. Individual committee members often rely both on staff forecast as well as on their privately formed views about which risks should be attached to staff forecast and additional privately collected information about state of the economy. It is assumed that for all P 's $\sigma_j = \sigma_P$ and that C has $\sigma_j = \sigma_C$. We assume that chairman has the same or higher capacity to collect private information than other committee members and hence the same or higher capacity to reduce noise. It follows that $\sigma_C \leq \sigma_P$.

Next we make strong assumption in order to make the model tractable. We assume that the whole committee learns previous state of the world at the beginning of each period before making next decisions, i.e. i_{t-1}^* is known by the time t period decision is being made. Alternative to the this assumption would be not to reveal i_{t-1}^* and have board members to use Kalman filtering to update their believes about the optimal interest rate. While possible we do not think this extension would add any substantive insight at the cost of greatly complicating the analysis.

Timing of events in period t is as follows: i) last period state of the world i_{t-1}^* is revealed, ii) nature determines all the random variables in the model hence setting i_t^* and all the signals of the

board members, iii) signals about the current state of the world i_t^j s are revealed to all members and remain their private information, iv) C makes proposal y_t , v) voting takes place between y_t and status-quo (i.e. last period policy) $x_t = p_{t-1}$ and winning alternative becomes new policy p_t and finally, vi) players collect their utilities and the decision making process moves to $t + 1$.

We will focus on Stationary Markov Perfect equilibrium in which strategies are measurable only with respect to payoff relevant variables (histories) and do not depend on time (Maskin and Tirole 2001). This allows us to drop the time subscripts and the notation becomes x for status-quo, y for proposal, i^* for previous period optimal interest rate, and i^j for signals about current optimal interest rate. Current optimal interest rate will be denoted by \bar{i}^* with the bar denoting variables that will become known in the next period (same applies to other variables, i.e. \bar{i}^j is signal about next period optimal interest rate player j receives at the beginning of next period). With this notation the $AR(1)$ process for the optimal interest rate becomes $\bar{i}^* = \rho i^* + \bar{u}$ and signals are determined according to $i^j = \bar{i}^* + \bar{v}^j$. Information set of each player j is thus $I_j = \{i^*, i^j\}$.

C 's strategy in this game is to offer a proposal depending on information set variables and denoted by $y(x, I_C)$ that maximizes her expected utility. It will be a solution to

$$U_C(x, I_C) = \max_{y \in Y} \mathbb{E}_M \left[-(p(x, y) - \bar{i}^*)^2 + \delta U_C(p(x, y), \bar{i}^*, \bar{i}^C) \mid I_C \right] \quad (1)$$

where δ is discount factor common to all board members, $p(x, y)$ denotes policy adopted depending on the status-quo x and proposal y . Set Y is assumed to be a set of discrete values in which interest rate can be set, i.e. Y is set of integer multiples of some value \bar{s} . Notation for the expectation operator $\mathbb{E}_M[\cdot]$ captures an idea that C will calculate her expectations differently based on a model of committee members' behaviour which we specify below. Finally, $U_C(x, I_C) = U_C(x, i^*, i^C)$ is C 's continuation value utility from a game starting with status-quo x , last period optimal interest rate i^* and signal about current optimal interest rate i^C .

Strategy of each P member j is simple binary decision to vote for or reject C 's proposal given status-quo x and all the remaining variables in information set I_j . We restrict attention to stage undominated strategies (Baron and Kalai 1993) in which player j simply votes for an alternative providing higher expected utility. This avoids equilibria in which players vote for an alternative they do not prefer simply because their vote cannot change the final decisions. Along with the assumption above this implies that j , given status-quo x , C 's proposal y and j 's signal i^j , votes

for y if and only if

$$\mathbb{E}_M [-(y - \bar{i}^*)^2 + \delta U_j(y, \bar{i}^*, \bar{i}^j) | I_j] \geq \mathbb{E}_M [-(x - \bar{i}^*)^2 + \delta U_j(x, \bar{i}^*, \bar{i}^j) | I_j] \quad (2)$$

where again $U_j(y, \bar{i}^*, \bar{i}^j)$ is a continuation value utility of player j from a game starting with status quo y , with previous period optimal interest rate \bar{i}^* and signal \bar{i}^j .

3.2 Committee members' behaviour

One possibility to proceed would be to assume full rationality on behalf of all the committee members in a standard sense, solve for the model equilibrium involving complicated expectation updating and signal extraction problems and then simulate path of decisions for random draw of model stochastic variables. However, presence of the information asymmetry among the board members along with the infinite horizon framework makes derivation of full solution unfeasible.

Besides technical complexity, such a model does not capture different modes or codes of conduct found among real world central bank committees (see Blinder 2004 or Chappell, McGregor and Vermilyea 2005 for discussion). For this reason we specify four different models of committee behaviour for which we solve for an equilibrium and then proceed with the simulations. First three models, which we label based on C 's behaviour as *democratic*, *consensual* and *opportunistic*, assume that the committee members do not take into account impact of their actions on their future decisions. Formally this is achieved by assuming $\delta = 0$. By making this assumption we break the first intertemporal link in the committee decision making mentioned above. Current policy still determines future status-quo, but the committee members do not take this fact into account. Last and fourth model, which we label *intertemporal democratic*, maintains the first intertemporal link but breaks the second one, i.e. assumes that the optimal monetary policy is independent across periods. Formally this is achieved by assuming $\rho = 0$ in the $AR(1)$ process determining optimal monetary policy rate \bar{i}^* . Below we describe the models with formal details relegated to the appendix.

Democratic model

In this model of committee behaviour chairman C plays a role of a democratic leader who's only special power is the proposal making one. Additionally C 's role is such that other committee members are free to express their own will through voting on her proposal and C 's behaviour has no effect on their own. In the language of our model each P members j is assumed to vote based on the voting rule (2) using information set $I_j = \{i^*, i^j\}$ and extracting no information content from C 's proposal. Given this behaviour, C solves her optimization problem (1) using

information $I_C = \{i^*, i^C\}$ and forming her expectation in a standard rational manner, i.e. the $\mathbb{E}_M[\cdot] = \mathbb{E}[\cdot]$ where $\mathbb{E}[\cdot]$ is standard expectation operator.

Consensual model

In this model chairman C is assumed to have dominant position beyond her proposal making power in that her dominant position makes other P members too keen to follow her wishes and adopt her point of view. Chairman, aware of this situation, does not pay attention to possible information other P members might possess. In the language of our model, C 's proposal is a solution to (1) given information $I_C = \{i^*, i^C\}$ but with the expectation operator $\mathbb{E}_M[\cdot]$ not taking into account the fact that possible rejection or acceptance of y contains information about unknown \bar{i}^* . In other words C 's proposal is policy in Y closest to C 's expectation of \bar{i}^* , i.e. closest to $\mathbb{E}[\bar{i}^* | i^*, i^C]$.

To capture the notion that the P members adopt C 's point of view, we assume that each P member j votes based on voting rule (2) but when calculating expected value of \bar{i}^* , j extracts information from C 's proposal. It is easy to see that the expectation can be written as $\mathbb{E}[\bar{i}^* | i^*, i^j, i^C \in \langle i_l^C, i_u^C \rangle]$ where i_l^C and i_u^C are lower and upper bounds on C 's signal respectively, as revealed by her proposal. We have decided to label this model consensual since by extracting information from C 's proposal level of heterogeneity of opinions within the committee is considerably reduced.

Opportunistic model

In this model we assume that C is opportunistic in consulting the other P members before the actual committee meeting. Once at the meeting C then knows most preferred policies of the remaining members and offers policy she knows would be adopted by supermajority of $\frac{N}{2} + 2$ of them. In terms of our model, we assume that C knows most preferred policy of each member j , which is a policy in Y closest to $\mathbb{E}[\bar{i}^* | i^*, i^j]$. Ordering those policies such that $y_1 \leq \dots \leq y_m \leq \dots \leq y_{N+1}$ where y_m is policy preferred by median committee member, offering policy adopted by supermajority of $\frac{N}{2} + 2$ amounts to, for $x \leq y_m$ case, offering y_{m-1} if $x \leq y_{m-1}$ and offering x if $x \geq y_{m-1}$. The case $x \geq y_m$ is analogous. An implicit assumption about behaviour of each P member j is that his voting is given by voting rule (2) with the expectation computed using information set $I_j = \{i^*, i^j\}$ and ignoring information content of C 's proposal.

This model is inspired by Riboni and Ruge-Murcia (2010) who in their empirical investigation of several descriptive monetary policy committee decision making models show that their ‘consensual’ model fits real world data best. In their model adopted policy is equal to the most preferred policy of a next-to-median member (side depending on the position of a status-quo) when this policy is sufficiently far away from the status-quo. When this policy is close to the status-quo, adopted policy is indeed the status-quo. This is what our opportunistic model does except that we label it differently as in our model it captures an idea that chairman’s objective is to offer a policy which would never be rejected and he achieves this by using his authority to consult individual committee members. Or in an alternative interpretation, to speak last during the committee discussion, after the remaining members expressed their preferred policies.

We have also experimented with opportunistic model in which C offers policy accepted by a mere majority $\frac{N}{2} + 1$ of members. Notice that this would be model often used in the literature as the accepted policy is equal to the policy most preferred by the median committee member. As the results were largely similar to the opportunistic model presented we do not report them.

Notice that the three models just described embed different degree of informational influence among chairman C and the remaining P members. In the democratic model there is little or no influence as C is not influenced by information P members have and they are not influenced by C ’s proposal. In the consensual model C is informationally independent while P members are influenced by her proposal. Finally, in the opportunistic model it is C who is influenced by the other P members by making her proposal based on their preferences and disregarding her own to a certain extend.

The tree models just explained are also related to some of the models found in existing literature. As already noted our opportunistic model is similar to the ‘consensual’ model of Riboni and Ruge-Murcia (2010). Our simple majority version of the opportunistic model mentioned above is similar to the ‘frictionless’ model in Riboni and Ruge-Murcia (2010), to the ‘individualistic’ model in Gerlach-Kristen (2008) and to the model in Weber (2008). In all those models the adopted policy is equal to the policy preferred by median committee member. Furthermore, our democratic model is similar to the ‘agenda-setting’ model of Riboni and Ruge-Murcia (2010) in that the chairman proposes policy that maximizes her expected utility among the policies she knows would be accepted. The key difference in our democratic model is that the acceptance is only in probabilistic as C does not know signals of the other committee members. Finally, our

consensual model is similar to the ‘autocratically collegial’ model in Gerlach-Kristen (2008) in that chairman proposes her most preferred policy and her authority makes the other committee members vote for her proposal. In the autocratically collegial model this is modelled as the other committee members having ‘tolerance interval’ around their preferred policy, in our model this is modelled as the other members taking chairman’s point of view by extracting information from her signal.

Intertemporal democratic model

This model is similar to the democratic model specified above in that each P committee member votes based on his private information only and does not extract any information from C ’s proposal with C solving her optimization problem in fully rational manner. As opposed to the democratic model, this model maintains the intertemporal link in the committee decision by assuming that all committee members take into account effect of their current behaviour on their future decisions, effect which works through current policy determining the future status-quo. Formally this is achieved by setting $\delta > 0$.

Key problematic aspect in simulating the equilibrium of this model is the fact that C ’s proposal strategy maps $\mathbb{R}^2 \times Y$ into Y and we would have to estimate the value functions $U_C(\cdot)$ at each point of this space. With standard value function iteration on discrete version of the $\mathbb{R}^2 \times Y$ the computational costs are prohibitive. To overcome this complication we set $\rho = 0$ breaking the intertemporal link in the optimal monetary policy. As a result the C ’s proposal strategies will be function of current status-quo x along with her signal i^C mapping $\mathbb{R} \times Y$ into Y which is considerably easier to simulate. We still have to derive equilibrium value function $U_j(\cdot)$ for all the board members, but we only need to know $U_j(\cdot)$ at a discrete and rather coarse set of points sufficient for numerical integration over \mathbb{R} as the Y set is already discrete.

3.3 Model simulations

For each version of the model of committee behaviour we generate 101 different random 100 period long paths. Those are chosen so as to gain insights into the results avoiding inference based either on a low number or on short paths while still keeping the simulations manageable. With simulation of one path in (intertemporal) democratic model taking approximately one hour for $N = 4$ on a standard desktop computer (twice as much for $N = 6$) we see the choice of number and length of paths as an appropriate trade-off between validity and manageability

(simulations of other models take considerably less time while simulations of intertemporal democratic model requires additional several days for estimation of continuation value function).

Along each path for every period we record status-quo x_t , proposal y_t and final policy p_t and calculate variable $skew_t$ as defined in the introductory part. It is given by

$$skew_t = \frac{\#(\text{voting for } y_t) \cdot y_t + \#(\text{voting for } x_t) \cdot x_t}{N + 1} - p_t \quad (3)$$

and allows us to run an ordered probit regression analogous to the one from the empirical part of the form

$$\Delta p_{t+1} = a_0 + a_1 skew_t + a_2 \Delta p_t + u_{t+1}. \quad (4)$$

In order to make the results more comparable among the different models, we keep values of the random variables fixed across simulations of those models. That is, when simulating, say, first path in the democratic model, random values in the model are the same as when simulating the first path in the consensual, opportunistic or democratic intertemporal model.

Following the discussion above, simulation values of parameters in the models are $\rho = 0.95$ and $\delta = 0$ for the democratic, consensual and opportunistic models and $\rho = 0$ and $\delta = 0.95$ for the intertemporal democratic model. In all the models we assume that the interest rate is set in steps of quarter of a percentage point, that is in all the models $\bar{s} = 0.25$.

Next we need to specify values for distributions of random shocks. Choice of σ_u is driven by our attempt to match standard deviation of changes in monetary policy rate in our empirical data. As p_t in our model eventually follows similar process as i_t^* , Δp_t will follow similar process as Δi_t^* . With the standard deviation of Δi_t^* equal to $\sqrt{2/(1+\rho)}\sigma_u$ and empirically observed standard deviation of changes in monetary policy rate between 0.25 and 0.5 we set σ_u to those two values.

For standard deviation of the board members' signals σ_P and σ_C we assume those to be either 0.25 or 0.5 implying that approximately 70% of board members' signals are within 25 or 50 basis points from the optimal interest rate.

From the values above we construct several scenarios. Our baseline scenario assumes $\sigma_u = 0.25$, $\sigma_C = 0.25$ and $\sigma_P = 0.25$. Interested in the comparative static properties, we further take $\sigma_u = 0.5$, $\sigma_C = 0.25$ and $\sigma_P = 0.25$ in 'high volatility' scenario, $\sigma_u = 0.25$, $\sigma_C = 0.5$ and $\sigma_P = 0.5$ in 'bad information' scenario and finally $\sigma_u = 0.25$, $\sigma_C = 0.25$ and $\sigma_P = 0.5$ in ' P

bad information' scenario. For the four scenarios just explained we simulate the models for both $N = 4$ and $N = 6$ in order to see an effect of increasing committee size on the results. We have chosen committee size of 5 and 7 as those are the most common central bank monetary policy committee sizes (Mahadeva and Sterne 2000).

3.4 Simulation results

Tables 1 through 3 show results of our simulation exercise. Besides estimates of coefficients a_1 and a_2 from (4) averaged over the 101 paths, we include average standard errors and average p-values. Row labelled *MSE* is average mean squared error between enacted and optimal monetary policy while row labelled *Votes proposal* is average number of votes for *C*'s proposal. Tables 1 and 2 show results for democratic, consensual, opportunistic and mechanical (see below) model for $N = 4$ and $N = 6$ respectively. Table 3 shows result for intertemporal democratic model.

Before proceeding to the discussion of our results we were interested to see whether we could generate the predictive power of *skew* with purely mechanical model. In this model, policy p in each period is equal to the policy in Y closest to the optimal policy \bar{i}^* and we calculate *skew* assuming that there is $d \in \{1, \dots, N/2\}$ dissenting members voting for status-quo x . We take d to be random variable drawn anew for each committee meeting with each value from $\{1, \dots, N/2\}$ being equally likely.

What is apparent from this mechanical model is that it cannot generate data in which *skew* holds information about future monetary policy changes. What the row MSE also shows is benchmark or minimal error in the monetary policy coming from the fact that the monetary policy rate is set in a discrete steps.

Looking at the democratic model results for baseline scenario and $N = 4$ in Table 1 average estimate of a_1 shows predictive power of *skew* variable for future policy changes. An intuition for this result is following. Assume that the optimal policy rate i^* has been constant for several periods to some value i_1^* and that the committee has been setting its policy p_1 to the same level. Assume now that the optimal policy rate increases to some value i_2^* . Committee members receive imperfect information about this shock and several courses of actions follow. If *C*'s signal does not prompt her to offer policy different from the current status-quo p_1 , new policy p_2 will be equal to the current status-quo and hence the *skew* variable will be equal to zero.

If, on the other hand, C offers proposal y_2 close to the new optimal policy rate i_2^* , her proposal will be higher than the current status-quo p_1 . Depending on votes of other committee members two possibilities arise. The first one is when C 's proposal is approved, new policy p_2 will then be approximately equal to the optimal rate i_2^* and the *skew* variable will be negative. But due to the fact that the optimal policy rate is $AR(1)$ process with relatively large ρ it is approximately equally likely that the optimal rate will increase or decrease in the future. With the monetary policy eventually following the optimal rate, it is then equally likely that the policy will increase or decrease in the future. The second possibility is when C 's proposal is rejected, new policy p_2 will then be equal to the status-quo p_1 and the *skew* variable will be positive. It is also more likely than not that the interest rate will increase in the future if it should follow the optimal rate. Combination of equal probability of increase and decrease in policy when *skew* < 0 and higher probability of increase when *skew* > 0 is what gives the positive estimate of a_1 .

The intuition just explained also reveals two conditions under which *skew* holds information about future policy changes. First condition is that the monetary policy cannot follow too closely or precisely the optimal rate. This is apparent from the estimates for the mechanical model. Second condition is that there has to be certain minimal degree of dissent in the committee. If all the committee members vote in a same way the *skew* variable will always be zero and hence cannot predict future policy changes. This is revealed by the estimates for the consensual and opportunistic models. In both of those models information is shared among the committee members and hence their decision making shows high degree of consensus. This is also apparent from the average votes for proposal which for both models is around 4.5 in a 5 member committee.

Nevertheless, the two conditions just explained are not enough for *skew* to be informative about future policy changes. Inspecting the first column of Table 1 for democratic model across different scenarios, predictive power of *skew* can disappear either in volatile economic environment (high volatility scenario) or in an environment in which central bankers possess imprecise information (bad information scenario). Comparing the results for bad information and P bad information scenarios then suggests that it is a precision in C 's signal that is important for the predictive power of *skew*.

The results for the other two models in Table 1, consensual and opportunistic one, as already noted do not predict any informational content in the *skew* variable, despite the fact that some

of the estimates for consensual model come close to statistical significance on average. This holds despite the fact that the policy in those models is on average further away from its optimum than in the democratic model, or in other words the first condition for *skew* to be informative explained above holds. What both of those models lack is the second condition, the independence in behaviour of the committee members.

We have already mentioned that high volatility of economic environment or a lot of noise in the information of committee member can render *skew* uninformative about future monetary policy changes even in the democratic model. However, turning our attention to Table 2 it is apparent that both effects can be overcome by increasing the committee size. Estimates of a_1 for the democratic model now become significant on average even in the high volatility and bad information scenarios. At the same time increase in the committee size does not change insignificance of estimates of a_1 in consensual and opportunistic models despite the fact that the average p-values increase for both models and all scenarios.

Finally with one exception average estimates of a_2 are not significant in Tables 1 and 2 suggesting that past changes in the interest rate do not predict future change in the interest rate in our model, despite the fact that some of the estimates for opportunistic and for two scenarios also for democratic model come close to statistical significance. As further discussed in the empirical part significant estimate of a_2 suggests interest rate smoothing motivation by the monetary policy committee. It is then not surprising that the estimates are not significant as the interest rate smoothing motivation is not build into any of the models.

Table 1 – Does the Voting Record Predict Policy Rate Changes?Estimates using simulated data with $N = 4$

$$\Delta p_{t+1} = a_0 + a_1 skew_t + a_2 \Delta p_t + u_{t+1}$$

Model	Democratic	Consensual	Opportunistic	Mechanical
Baseline scenario ($\sigma_u = 0.25, \sigma_C = 0.25, \sigma_P = 0.25$)				
Skew (a_1)	4.10 *	5.93	5.25	0.60
	[1.63] (0.089)	[3.29] (0.175)	[6.40] (0.418)	[3.99] (0.435)
Lagged policy change (a_2)	0.75	0.07	1.63	-0.14
	[0.53] (0.259)	[0.45] (0.520)	[0.74] (0.108)	[1.26] (0.451)
MSE	0.027	0.033	0.033	0.005
Votes proposal	2.92	4.64	4.83	---
High volatility scenario ($\sigma_u = 0.5, \sigma_C = 0.25, \sigma_P = 0.25$)				
Skew (a_1)	2.19	2.59	0.69	0.21
	[1.04] (0.124)	[2.43] (0.364)	[3.65] (0.585)	[2.05] (0.444)
Lagged policy change (a_2)	0.24	0.01	0.60	0.00
	[0.24] (0.362)	[0.21] (0.515)	[0.29] (0.112)	[0.64] (0.462)
MSE	0.043	0.049	0.044	0.005
Votes proposal	3.46	4.62	4.78	---
Bad information scenario ($\sigma_u = 0.25, \sigma_C = 0.5, \sigma_P = 0.5$)				
Skew (a_1)	3.43	6.84	6.05	---
	[1.50] (0.106)	[3.59] (0.148)	[6.47] (0.385)	---
Lagged policy change (a_2)	0.29	0.08	1.04	---
	[0.48] (0.435)	[0.46] (0.507)	[0.64] (0.203)	---
MSE	0.048	0.052	0.053	---
Votes proposal	3.00	4.69	4.85	---
P bad information scenario ($\sigma_u = 0.25, \sigma_C = 0.25, \sigma_P = 0.5$)				
Skew (a_1)	4.97 *	9.98	6.53	---
	[1.79] (0.055)	[6.24] (0.228)	[6.43] (0.356)	---
Lagged policy change (a_2)	0.82	-0.19	1.25	---
	[0.54] (0.228)	[0.42] (0.490)	[0.67] (0.128)	---
MSE	0.041	0.036	0.049	---
Votes proposal	2.74	4.88	4.84	---

Note: Average ordered probit estimates over 101 random 100 period long paths. [Average standard errors] and (average p-value). * statistically significant at 10% level, ** statistically significant at 5% level, *** statistically significant at 1% level based on average p-value. MSE is average mean squared difference between adopted and optimal policy. Votes proposal is average number of votes for chairman's proposal.

Table 2 – Does the Voting Record Predict Policy Rate Changes?

Estimates using simulated data with $N = 6$

$$\Delta p_{t+1} = a_0 + a_1 skew_t + a_2 \Delta p_t + u_{t+1}$$

Model	Democratic	Consensual	Opportunistic	Mechanical
Baseline scenario ($\sigma_u = 0.25, \sigma_C = 0.25, \sigma_P = 0.25$)				
Skew (a_1)	5.15 ** [1.66] (0.025)	6.57 [3.30] (0.156)	7.41 [5.30] (0.256)	0.01 [3.45] (0.510)
Lagged policy change (a_2)	1.08 [0.56] (0.125)	0.14 [0.46] (0.490)	2.05 * [0.81] (0.065)	-0.30 [1.06] (0.541)
MSE	0.026	0.032	0.030	0.005
Votes proposal	3.90	6.46	6.62	---
High volatility scenario ($\sigma_u = 0.5, \sigma_C = 0.25, \sigma_P = 0.25$)				
Skew (a_1)	2.37 * [1.02] (0.085)	3.01 [2.43] (0.328)	1.69 [2.99] (0.449)	-0.03 [1.76] (0.521)
Lagged policy change (a_2)	0.28 [0.24] (0.311)	0.02 [0.21] (0.499)	0.63 [0.30] (0.115)	-0.07 [0.54] (0.551)
MSE	0.040	0.049	0.036	0.005
Votes proposal	4.66	6.42	6.52	---
Bad information scenario ($\sigma_u = 0.25, \sigma_C = 0.5, \sigma_P = 0.5$)				
Skew (a_1)	3.57 * [1.47] (0.079)	7.60 [3.67] (0.140)	7.44 [5.09] (0.261)	--- ---
Lagged policy change (a_2)	0.40 [0.49] (0.421)	0.15 [0.47] (0.460)	1.16 [0.65] (0.184)	--- ---
MSE	0.047	0.052	0.051	---
Votes proposal	4.04	6.54	6.67	---
P bad information scenario ($\sigma_u = 0.25, \sigma_C = 0.25, \sigma_P = 0.5$)				
Skew (a_1)	5.31 ** [1.71] (0.032)	12.42 [6.61] (0.174)	7.86 [5.08] (0.231)	--- ---
Lagged policy change (a_2)	1.00 [0.55] (0.147)	-0.13 [0.42] (0.517)	1.36 [0.68] (0.128)	--- ---
MSE	0.041	0.036	0.048	---
Votes proposal	3.66	6.82	6.66	---
Notes: See table 1.				

**Table 3 – Does the Voting Record Predict Policy Rate Changes?
Estimates using simulated data**

$$\Delta p_{t+1} = a_0 + a_1 skew_t + a_2 \Delta p_t + u_{t+1}$$

Model	Intertemporal Democratic	
	$N = 4$	$N = 6$
Baseline scenario ($\sigma_u = 0.25, \sigma_C = 0.25, \sigma_P = 0.25$)		
Skew (a_1)	1.98 [1.64] (0.338)	2.36 [1.66] (0.271)
Lagged policy change (a_2)	-2.31 *** [0.56] (0.002)	-2.23 *** [0.58] (0.008)
MSE	0.028	0.027
Votes proposal	2.89	3.89
Notes: See table 1.		

Before we conclude the theoretical section we turn our attention to the results for intertemporal democratic model. Table 3 shows the simulation results for this model and baseline scenario for both, $N = 4$ and $N = 6$. We have decided not to include more results as those come with considerable time costs and even the estimates for the baseline scenario show main weakness of this model which is negative estimate of a_2 . Intuitively this result is driven by the fact that $\rho = 0$. When the optimal rate increases to some value and the monetary policy follows it, giving positive policy change, it is highly likely that in the next period monetary policy will have to be reversed as the optimal rate is normally distributed around zero for $\rho = 0$. Additionally, average estimate of a_1 in table 3 is not significant showing that breaking the intertemporal link in the optimal interest rate renders the *skew* variable uninformative about future monetary policy.

Overall, the model delivers several interesting policy implications. First, publishing voting pattern of monetary policy committee members is important if the monetary policy is not always at its optimal level. This allows other economic agents to gain information about future course of monetary policy in the form of the *skew* variable.

Second, informativeness of the *skew* variable is not guaranteed automatically. What is needed is informational independence of the committee members. If all the committee members behave based on the same information or one of the committee members has enough authority for the other committee members to adopt his or her point of view, high degree of consensus results and the *skew* variable is rarely different from zero.

Third, even with independently behaving central bankers the *skew* variable might not be informative. In a volatile economic environment or when the monetary policy committee members possess imprecise information, it is important for the committee to have sufficient number of members, as every additional committee member brings new information.

4 Institutional Background

This section gives information on the background of central bank committees' decision making about monetary policy. The bank boards typically meet on a monthly frequency and decide on the level of the repo rate. The frequency of monetary policy meetings vary. For example, the Bank of England and the Hungarian central bank meet monthly, the Czech National Bank used to meet monthly up to 2007 and meets eight times a year from 2008 onwards as the U.S. Fed. Occasionally, the central banks hold extraordinary policy meetings.

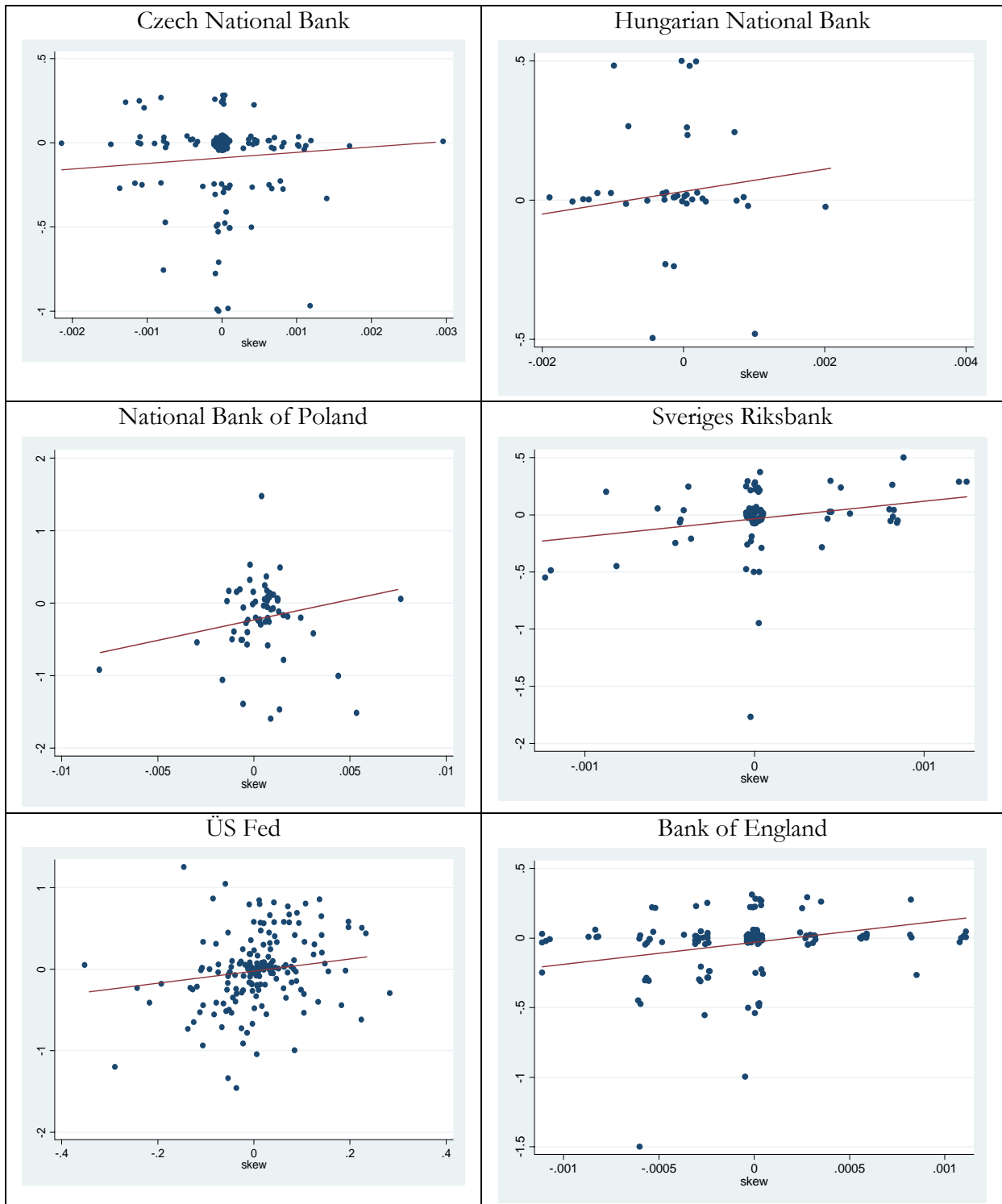
The boards take decisions based on majority vote. In the event of a tie, the chairperson (governor, if present at the meeting) shall have the casting vote. The policy decision is announced on the same day. Minutes explaining their monetary policy decision, i.e. the voting of central bankers, are published approximately with a one or two weeks lag. Except Poland, the voting record is an integral part of minutes and summarizes the qualitative information contained in minutes. In case of Poland, the voting record does not appear sooner than 6 weeks (and no later than after 12 weeks) after the policy meeting.² Therefore, Poland case provides us with the first natural experiment setup, where we can examine whether committee members put enough effort into collecting private information when they know that voting record will be released with a considerable time lag. Our results show that this is indeed the case and that the voting record does not lose its predictive power when not published. This leads us to propose that a timely release of voting record would be beneficial to both sides, financial markets who would gain access to additional information as well as to committee members who can demonstrate good quality of their work to public. This is reconfirmed also for the U.S. case, when we use the data for 1970-1996 (Burns and Greenspan chairmanship) collected and coded by Chappell et al. (2005).

² More specifically, if the repo rate was changed, the voting record is first published in the Court and Economic Gazette of the Ministry of Justice and only after that in the inflation report. Voting records in the Court and Economic Gazette have to be published not sooner than 6 weeks and no later than 12 weeks after voting took place.

Voting results are typically attributed, but not always. For example, the voting ratio without an explicit statement on how individual board members voted was released for the monetary policy decisions in 2001-2007 in the Czech Republic. From mid-2000 to January 2006 the (unattributed) voting record was published in the minutes only, while since February 2006 the voting record has been released already at the press conference that is held about 3 hours after the announcement of the interest rate decision. In addition, the Czech National Bank has recently published the transcripts of its monetary policy meetings from 1998–2001, which include the voting record as well. Hence, the Czech case offers us the second natural experiment set-up in which we can test whether the voting ratio has similar predictive power to full voting record. The results will show that this is the case. The lesson learnt from the Czech case is therefore to publish at least voting ratio if considerations regarding the names are serious.

U.S. institutional background to be described.

Figure 1 – Actual Voting Record Skew and Future Policy Rate Change



Note: Skew is calculated as the difference between the average repo rate voted by individual members of board and actual repo rate at the next meeting is plotted on x-axis. Future monetary policy rate change is plotted on y-axis. The jitter is used for the overlapping observation for expositional purposes.

The disagreement among central bankers is common. The voting was not unanimous in 46% in the case of the Czech central bank, in 70% in the case of Hungarian central bank, in 90% in the case of Polish central bank, in 19% in case of Swedish central bank, in 59% in case of Bank of England during our sample period. The frequency of unanimous voting depends on the size of bank board, to a certain extent, with Hungary and Poland having more than 10 members in the board at the end of sample. The typical magnitude of monetary policy rate change is 25 basis points. Other magnitudes are less common even though central banks decreased the policy rates quite aggressively during the recent financial crisis and often by 50 or even 100 basis points at the meeting. Substantive changes of policy rate of similar magnitude were also observed in the Czech Republic, Hungary and Poland during the transition period to market economy characterized by more volatile macroeconomic development. Data are further described in Appendix A2 and A3.

5 Empirical Methodology

Our theoretical model shows when the voting record is likely to be informative for the future policy changes. As regards the empirical methodology we follow the approach developed by Gerlach-Kirsten (2004) to assess the predictions of our model. Gerlach-Kirsten (2004) analyses the voting record of the MPC of the Bank of England over the period 1997–2002, while we aim to include relevant data from additional central banks to provide a more comprehensive international comparison. More specifically, we focus on the following five countries that conduct their policies within an inflation targeting regime: the Czech Republic, the United Kingdom, Hungary, Poland and Sweden. For comparison, we estimate similar models for the U.S.

Following Gerlach-Kirsten (2004), we define a measure of disagreement in the bank board, the variable *skew* as

$$skew_t = average(i_{j,t}) - i_t \quad (5)$$

where $i_{j,t}$ is the interest rate voted for by bank board member j at a monetary policy meeting at time t and i_t denotes the monetary policy rate. In consequence, a positive value of *skew* indicates that some bank board members voted in favour of a higher rate than the majority. To assess whether the voting record reveals information on future monetary policy, we estimate a following baseline regression model for each individual country separately.

$$\Delta i_{t+1} = a_0 + a_1 skew_{\tau(t)} + a_2 \Delta i_t + u_{t+1} \quad (6)$$

It is assumed in (6) that the interest rate decision is taken at time t , the votes are released at time $\tau(t)$, i.e. in the period between the interest rate decisions at t and $t + 1$ (often together with the minutes, typically about two weeks after the interest rate decision at t ; it is noteworthy to emphasise that we focus on the voting record, as this is the only quantitative information in the minutes; alternatively one would have to classify the qualitative information contained in the minutes). We estimate (6) by an ordered probit technique to reflect the discrete nature of monetary policy rate changes. It is important to emphasize that the discrete dependent variables has been stacked in less categories, as some magnitudes of policy changes such as by 75 basis points happened rarely. Therefore, the dependent variable was coded in four to five categories depending on the country and defined as follows: large decrease, decrease, no change, hike and large hike (-50, -25, 0, +25 and +50 basis point changes respectively).³

According to our theoretical model, the coefficients a_1 and a_2 are expected to take positive values. As regards the sign of a_1 , if some bank board members favour higher rates, *skew* is positive and a future interest rate hike is more likely, conditional upon the voting record being informative for future policy. As regards the coefficient a_2 , it reflects interest rate smoothing and the attempt of central bankers to avoid sudden policy reversals. If a_1 is significant, we can imply that releasing voting record improves the predictive power of a “naive” model of future interest rate changes in which public assumes only smoothing and reactions to shocks.

Our second baseline model extends this naive model by assuming that financial markets work with larger information set than the naive model. We approximate their information set from yield curve. If the financial market has identical information set and evaluates the information at least as effectively as the central bank, expectations about future policy should be built into the slope of the term structure of interest rates or reflected in interest rate futures. In that case, parameter b_1 would be insignificant in our second baseline model. In the opposite case, voting record reveals additional information to financial market and improves predictability of monetary policy. In addition, *skew* could be insignificant in the case of some institutional drawbacks in the way how central bank votes or communicates to markets. To assess these considerations formally, we estimate a regression of the following form:

³ The number of categories is set according to the log-likelihood of competing models. An alternative way would be to test, whether the thresholds estimated within the ordered probit model differ significantly from each other.

$$\Delta i_{t+1} = b_0 + b_1 skew_{\tau(t)} + b_2 \Delta i_t + b_3 (i_{\chi(t),L} - i_{\chi(t),S}) + u_{t+1} \quad (7)$$

As compared to (6), equation (7) now includes an additional term to control for financial market expectations. $i_{\chi(t),L} - i_{\chi(t),S}$ represents the slope of the term structure, where L and S denote the respective money market maturities⁴ and it is assumed that $L > S$ (following Gerlach-Kirsten, 2004, we will consider various maturities). $\chi(t)$ denotes the time period between the interest rate decisions and the data on $i_{\chi(t),L}$ and $i_{\chi(t),S}$ will be from the day before the release of the voting record (thus, $\chi(t) < \tau(t)$).

Regarding our two natural experiment set-ups, we may test whether *skew* is informative in the period when voting records are disclosed with a considerable time lag, as in the aforementioned case of Poland and the U.S.. We may also test whether voting ratio is informative when only unattributed voting records were available, as in the aforementioned case of the Czech Republic.

We add two robustness checks to our baseline models. First, we extend the empirical specification by Gerlach-Kirsten (2004) by including the measure of dispersion in voting records that may serve as an indicator of the degree of uncertainty the board members face. We measure the dispersion of voting results by the standard deviation of individual votes.⁵

$$\Delta i_{t+1} = b_0 + b_1 skew_{\tau(t)} + b_2 \Delta i_t + b_3 (i_{\chi(t),L} - i_{\chi(t),S}) + b_4 dispersion_t + u_{t+1} \quad (8)$$

The sign of b_4 is not clear-cut. On the one hand, more uncertainty can be associated with more cautious monetary policy. On the other hand, more uncertainty may trigger more active monetary policy responses (Soderstrom, 2002).

Second, we also estimate the Eq. (7) based on the data before the 2008-2009 financial crisis in order to test the sensitivity of the results.

Finally, we estimate the empirical model for the U.S. Fed, where we include in addition the skew for alternate members – i.e. skew for alternate board members, which do not have voting power and well as the committee bias. The committee bias is an official statement of the Fed on how

⁴ An alternative would be to include interest rate futures or forwards, but these were not available for all sample countries.

⁵ The share of largest minority could serve as an alternative measure.

the Fed is leaning in terms of its next interest rate move and the variable is coded in the way that the higher value of variable indicates the move of interest rates in upward direction.

6 Empirical Results

This section gives the empirical results on whether the voting record improves monetary policy predictability. We first present our baseline estimates (Eqs. (5) and (6)) for all countries. Alternative specifications follow.

Table 4 – Does the Voting Record Predict Repo Rate Changes?
Baseline estimates

$$\Delta i_{t+1} = b_0 + b_1 skew_{\tau(t)} + b_2 \Delta i_t + b_3 (i_{\chi(t),L} - i_{\chi(t),S}) + u_{t+1}$$

Country	Czech Rep.		Hungary		Poland		Sweden		UK	
Sample	2000:7-2008:12		2005:10-2009:2		2000:2-2008:12		1999:1-2009:2		1997:6-2009:2	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Lagged repo changes (b_2)	1.34*** (0.27)	0.46 (0.42)	1.44*** (0.32)	0.97*** (0.38)	0.64*** (0.12)	0.15 (0.19)	1.03*** (0.19)	0.87*** (0.21)	0.87*** (0.23)	0.99*** (0.19)
Skew (b_1)	1.74*** (0.33)	1.14*** (0.40)	0.62* (0.33)	0.62* (0.33)	0.31*** (0.09)	0.34*** (0.12)	1.58*** (0.36)	1.27*** (0.39)	1.22*** (0.39)	1.58*** (0.29)
Term structure (b_3)		2.53** (1.15)		3.92*** (1.36)		3.43*** (0.65)		1.26* (0.74)		1.52*** (0.49)
Adj. pseudo R-squared	0.24	0.20	0.34	0.49	0.16	0.41	0.24	0.25	0.20	0.32
Observations	100	75	40	40	60	60	90	90	142	142

Note: * statistically significant at 10% level, ** statistically significant at 5% level, *** statistically significant at 1% level. Standard errors in parentheses. Ordered probit estimation. Term structure stands for the difference between 1Y and 3M interbank rate in given country. The data in the Czech Republic in column 2 only until 2006:7.

The results reported in Table 4 suggest that the voting record is indeed informative about future policy rate changes. Lagged repo rate change is typically significant suggesting the central bank smooth interest rates, to a certain extent, and tries to avoid sudden reversals in their policies. The variable *skew* is statistically significant at conventional levels in all countries in the first baseline “naive” model as well as in the second baseline model with financial market expectations. The pseudo R-squared, the measure of regression fit, varies from 0.16 to 0.49. Our results for the U.K. confirm the previous empirical findings by Gerlach-Kirsten (2004). The significance of *skew* indicate that the democratic version of our theoretical model describes the real world data most closely. In other words, this suggest that the chairmen in these central banks likely act as a democratic leader who’s only special power is the proposal making one and other committee members are free to express their own will through voting on the proposal of chairmen.

In the case of Poland where voting record is published with a significant lag separately from minutes and is not available before the next policy meeting, the *skew* carries additional information not available to the financial markets. The adjusted pseudo R-squared increases from 0.35 in the specification with lagged policy rate changes and term structure to 0.41 in the case of specification with lagged policy rate changes, term structure and *skew*. We therefore conclude that despite the time lag committee members collect as much private information as if they knew voting would be published soon. Also, releasing voting records faster would be beneficial for both public as well as central bank.

The results for the Czech Republic use the data until 2006:7 in the specification with the financial market expectations (column 2 in Table 4). The reason is that from this period the voting record was released only about 3 hours after the monetary policy decision was announced. The monetary policy decision was typically announced around 1PM and the voting ratio was released at around 3.30PM at the press conference. In principle, we could collect interbank rates at say 2PM and therefore use more recent data as well, but it has to be emphasized that the interbank market was not very liquid during financial crisis. Therefore, we preferred to restrict the sample to 2006:7. The results for the Czech Republic also point to the fact that publishing voting ratio (without attributed voting record) may be sufficient to better understanding of future course of monetary policy.

Table 5 – Does the Voting Record Predict Repo Rate Changes?
Alternative specifications – Different Maturities in Term Structure and Uncertainty
 $\Delta i_{t+1} = b_0 + b_1 skew_{\tau(t)} + b_2 \Delta i_t + b_3 (i_{\chi(t),L} - i_{\chi(t),S}) + b_4 dispersion_t + u_{t+1}$

Country	Czech Rep.		Hungary		Poland		Sweden		UK	
Sample	2000:7-2008:12		2005:10-2009:2		2000:2-2008:12		1999:1-2009:2		1997:6-2009:2	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Lagged repo changes (b_2)	0.08 (0.43)	0.45 (0.42)	1.22*** (0.37)	0.88** (0.40)	0.23 (0.16)	0.17 (0.19)	0.92*** (0.19)	0.87*** (0.21)	1.15*** (0.18)	0.99*** (0.19)
Skew (b_1)	0.89** (0.41)	1.14*** (0.40)	0.50* (0.28)	0.48 (0.36)	0.33*** (0.12)	0.31*** (0.11)	1.48*** (0.37)	1.29*** (0.41)	1.70*** (0.29)	1.54*** (0.31)
Term structure (b_3)	10.24*** (2.87)	2.48** (1.15)	2.10 (1.96)	4.67*** (1.73)	4.83*** (0.88)	3.67*** (0.69)	3.23** (1.45)	1.24* (0.74)	0.41*** (0.67)	1.58*** (0.50)
Dispersion (b_4)		-0.93 (2.54)		-7.88* (4.51)		1.54 (1.32)		0.93 (2.85)		-3.99* (2.28)
Adj. pseudo R-squared	0.27	0.20	0.35	0.54	0.39	0.41	0.27	0.25	0.29	0.33
Observations	75	75	40	40	60	60	90	90	142	142

Note: * statistically significant at 10% level, ** statistically significant at 5% level, *** statistically significant at 1% level. Standard errors in parentheses. Ordered probit estimation. Term structure stands for the difference between 3M and 1M, resp. 1Y and 3M interbank rate in odd, resp. even columns in given country. The data in the Czech Republic in columns 1 and 2 only until 2006:7. Uncertainty stands for the standard deviation of individual votes in the bank board.

We have also carried out a number of robustness checks. In the baseline specifications, the term structure was defined as the difference between 12 months and 3 months interbank rate. Alternatively, the term structure is based on different maturities, in the regressions presented in Table 5 defined as the difference between 3 months and 1 month interbank rate. The results remain largely unchanged. The *skew* remains statistically significant and the estimated size of its parameter is largely similar. Similarly, introducing the dispersion, a measure of disagreement in the board, as additional explanatory variable does not change the interpretation of the baseline estimates. The dispersion is statistically significant at 10% level in Hungary and the U.K. This suggests that more dispersed opinion about the policy rates is associated with loosening of the policy in these two countries. The dispersion is insignificant in other countries. Table 6 reports the results based on sample without financial crisis period (up to 2007:8). Again, the results remain largely stable.

Table 6 – Does the Voting Record Predict Repo Rate Changes?
Alternative specifications – Data until Financial Crisis Only
 $\Delta i_{t+1} = b_0 + b_1 skew_{\tau(t)} + b_2 \Delta i_t + b_3 (i_{\chi(t),L} - i_{\chi(t),S}) + u_{t+1}$

Country	Czech Rep.		Hungary		Poland		Sweden		UK	
Sample	2000:7-2007:7		2005:10-2007:7		2000:2-2007:7		1999:1-2007:7		1997:6-2007:7	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Lagged repo changes (b_2)	1.24*** (0.31)	0.46 (0.42)	1.50*** (0.47)	1.22 (0.80)	0.56*** (0.13)	0.15 (0.20)	1.01*** (0.23)	0.67*** (0.27)	0.99*** (0.21)	0.46* (0.25)
Skew (b_1)	1.66*** (0.35)	1.14*** (0.40)	0.47 (0.47)	1.94** (0.92)	0.28*** (0.09)	0.34*** (0.12)	1.39*** (0.28)	0.84* (0.44)	1.57*** (0.29)	1.28*** (0.32)
Term structure (b_3)		2.53** (1.15)		8.08** (3.19)		3.47*** (0.76)		2.24** (0.88)		2.99*** (0.68)
Adj. pseudo R-squared	0.19	0.20	0.35	0.71	0.13	0.41	0.24	0.25	0.23	0.33
Observations	87	75	22	22	46	46	79	79	123	123

Note: * statistically significant at 10% level, ** statistically significant at 5% level, *** statistically significant at 1% level. Standard errors in parentheses. Ordered probit estimation. Term structure stands for the difference between 1Y and 3M interbank rate in given country. Data until 2007:7 to exclude the period with global financial crisis. The data in the Czech Republic in column 2 only until 2006:7.

The results for the U.S. Fed support our findings for the inflation targeting countries. Skew is statistically significant in all cases at 1% level even with the measure of committee bias, which in principle carries the same piece of information. On the other hand, the skew alternative is not significant, see Table 8.

Table 7 – Does the Voting Record Predict Repo Rate Changes in the US?
Chappell et al. (2005) data for Burns and Greenspan era

$$\Delta i_{t+1} = b_0 + b_1 skew_{\tau(t)} + b_2 \Delta i_t + b_3 (i_{\chi(t),L} - i_{\chi(t),S}) + b_4 dispersion_t + u_{t+1}$$

Country	Full sample		Burns era		Greenspan era		Greenspan era	
Sample	1970:2-1996:12		1970:2-1978:2		1987:8-1996:12		1987:8-1996:12	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Lagged repo changes (b_2)	0.42*** (0.07)	0.42*** (0.07)	0.45*** (0.08)	0.45*** (0.09)	0.41*** (0.13)	0.38*** (0.12)	0.11 (0.15)	0.06 (0.15)
Skew (b_1)	4.59*** (1.02)	4.61*** (1.02)	2.85** (1.12)	2.87*** (1.12)	12.25*** (2.64)	12.54*** (2.65)	9.19*** (2.83)	8.79*** (2.90)
Dispersion (b_4)		0.53 (0.85)		0.20 (1.08)		1.14 (2.01)		2.70 (2.14)
Committee bias (b_3)							1.08*** (0.28)	1.19*** (0.28)
Adj. pseudo R-squared	0.12	0.12	0.13	0.13	0.18	0.18	0.27	0.28
Observations	172	172	98	98	74	74	74	74

Note: * statistically significant at 10% level, ** statistically significant at 5% level, *** statistically significant at 1% level. Standard errors in parentheses. Ordered probit estimation. Committee bias indicates how the Fed is leaning in terms of its next interest rate move and the variable is coded in the way that the higher value of variable indicates the move of interest rates in upward direction.

**Table 8 – Does the Voting Record Predict Repo Rate Changes in the US?
Chappell et al. (2005) data for Burns and Greenspan era
Skew for Alternate Members Added**

$$\Delta i_{t+1} = b_0 + b_1 skew_{\tau(t)} + b_2 \Delta i_t + b_3 (i_{\chi(t),L} - i_{\chi(t),S}) + b_4 dispersion_t + u_{t+1}$$

Country	Full sample		Burns era		Greenspan era		Greenspan era	
Sample	1970:2-1996:12		1970:2-1978:2		1987:8-1996:12		1987:8-1996:12	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Lagged repo changes (b_2)	0.42*** (0.09)	0.42*** (0.07)	0.45*** (0.09)	0.45*** (0.09)	0.38*** (0.12)	0.37*** (0.12)	0.07 (0.15)	0.05 (0.15)
Skew (b_1)	4.62*** (1.02)	4.61*** (1.02)	2.89*** (1.12)	2.90*** (1.12)	11.39*** (3.36)	10.88*** (3.44)	11.21*** (3.50)	10.39*** (3.59)
Skew – alternates (b_1)	0.09 (0.15)	0.08 (0.14)	0.06 (0.15)	0.05 (0.15)	1.16 (1.79)	1.37 (1.82)	-1.82 (1.99)	-1.53 (2.02)
Dispersion (b_4)		0.51 (0.85)		0.17 (1.08)		1.39 (2.04)		2.48 (2.16)
Committee bias (b_3)							1.22*** (0.29)	1.26*** (0.30)
Adj. pseudo R-squared	0.12	0.12	0.13	0.13	0.19	0.19	0.28	0.29
Observations	172	172	98	98	74	74	74	74

Note: * statistically significant at 10% level, ** statistically significant at 5% level, *** statistically significant at 1% level. Standard errors in parentheses. Ordered probit estimation. Committee bias indicates how the Fed is leaning in terms of its next interest rate move and the variable is coded in the way that the higher value of variable indicates the move of interest rates in upward direction. Skew alternates - defined as the difference between the average policy rate voted by individual alternate committee members and the policy rate that is the outcome of the majority vote. Note that even though alternates members are not voting members, but they actively participate in discussions during monetary policy meeting.

All in all, the results suggest that the voting record bears relevant information about future monetary policy for all countries in our sample and in consequence, serves as a useful tool for improving the predictability of monetary policy.

7 Concluding Remarks

In this paper, we examine whether the voting records of central bank boards are informative about future monetary policy. We approach this issue from two angles. First, we develop a theoretical model of central bank decision making, where board members have non-homogeneous information sets and try to set policies as to match uncertain ‘state of the world’. The model contains an intertemporal link between decisions taken at different board meetings to reflect the nature of monetary policy making in which interest rate adopted during one board meeting becomes a status-quo for the next board meeting. The model also assumes an intertemporal link in optimal policies that change only slowly over time. We investigate whether voting pattern can predict future changes in the interest rate based on data simulated from this model. The three different versions of model are estimated with simulated data: 1) democratic, 2) consensual and 3) opportunistic. In principle, these versions differ in the extent how chairman influences the voting of other board members with the chairman allowing democratically to

express the opinion of other board members in 1) and thus sufficient independence in voting across board members exist, having a dominant position to force consensus in 2) and voting opportunistically according to the majority of other board members in 3). The results show that the democratic version of our model is able to generate the significant correlations between voting pattern and future policy changes.

Second, the model predictions are tested on real data. For this reason, data on six countries (the Czech Republic, Hungary, Poland, Sweden, the United Kingdom and the United States) that release its voting records are collected and it is found that in all countries the voting records indeed contain information relevant about future monetary policy and thus in principle improve monetary policy predictability. More specifically, it is found that if a minority votes for higher rates than the majority, it is more likely that there will be a rate hike in the following meeting. This result is robust to controlling for financial market expectations as well as different sample periods. The results for Poland (as well as for U.S. under Burns and Greenspan chairmanship) suggest that committee members tend to put the same effort into forming their views no matter whether their voting is published soon after the meeting or after a longer period of time. Hence, releasing voting records faster would be beneficial for both public as well as central bank who could gain credibility.

All in all, monetary policy predictability can be improved by releasing the voting record in a timely fashion. Similarly to Gerlach-Kristen (2004) the results in this paper hold regardless whether the voting record is attributed or not. In consequence, in case of concern that attributed voting records may expose individual board members to some external pressure (such as in case of monetary union with board members not voting for national interests), the voting results can be published non-attributed and still contribute to better understanding of monetary policy.

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APPENDIX

A1 Derivation of Central Bank Board Decision Making Model

In this appendix we explain models from the main part of the paper in more detail so that it becomes apparent how to generate C 's proposals and P 's voting behaviour. We further explain several aspects of our simulation exercise and methods we used.

First note that for all the models the equilibrium exists. For the three models with $\delta = 0$ the equilibrium exists which can be established using simple backward induction argument. As there is no intertemporal link in the decisions, we can focus on a single period. Within this period P members move last and their behaviour is given by the specified voting condition. Knowing this C derives her proposal y as a solution to her optimization problem. Finally, for the intertemporal democratic model note that the policy space is finite and the existence of Stationary Markov Perfect equilibrium follow from arguments in Maskin and Tirole (2001).

Throughout the explanation we will often work with a vector of random variables in our model. All those form a random vector $r = \{\bar{i}^*, i^{P1}, \dots, i^{PN}, i^C\}'$ that has multivariate normal distribution with, conditional on information embedded in i^* , mean equal to ρi^* and variance-covariance matrix equal to matrix with vector $\{\sigma_u^2, \sigma_u^2 + \sigma_P^2, \dots, \sigma_u^2 + \sigma_P^2, \sigma_u^2 + \sigma_C^2\}$ on the main diagonal and all the off-diagonal elements equal to σ_u^2 . Often we will need to compute conditional expectation of r given specific value of one or more of its elements. For this we use well known result for multivariate normal distribution that states that for vector of (possibly more than two) random variables $\{x_1, x_2\}'$ distributed according to $N(\mu, \Sigma)$ with $\mu = \{\mu_1, \mu_2\}'$ and $\Sigma = \begin{pmatrix} \sigma_{11} & \sigma_{12} \\ \sigma_{21} & \sigma_{22} \end{pmatrix}$ where the partitioning of μ and Σ conforms to partition of $\{x_1, x_2\}'$, conditional distribution of x_1 given specific value of x_2 is $N(\mu'_1, \sigma'_{11})$ where $\mu'_1 = \mu_1 + \sigma_{12}\sigma_{22}^{-1}(x_2 - \mu_2)$ and $\sigma'_{11} = \sigma_{11} - \sigma_{12}\sigma_{22}^{-1}\sigma_{21}$.

To simulate each of the models, we start in the first period with previous optimal interest rate and monetary policy rate being zero. In simulations of the democratic, consensual and opportunistic models we restrict the policy space to be in $\langle -10, 10 \rangle$ interval so that with our choice of \bar{s} the policy space is equal to $Y = \{-10, -9.75, \dots, 9.75, 10\}'$. For intertemporal democratic mode we restrict the policy space to be in $\langle -3.5, 3.5 \rangle$ for the baseline scenario. We

do not need to look at a larger policy space as the optimal interest rate and players' signals stays well away from its border. As explained in the text it is also inconsequential that we allow the optimal interest rate and the monetary policy rate to attain negative values as all the results and estimates are invariant to adding a constant to the optimal interest rate.

Values of random variables used in the simulations are kept constant across the different models. That is, when we simulate, say, first path for the baseline scenario of the democratic model, the random variables used are the same when simulating first path of any other scenario for the same model or of any other model for the same scenario. This holds even across the $N = 4$ and $N = 6$ simulations where we naturally have to add two more random variables for the two extra players, but the remaining random variables are kept the same.

In the democratic model with $\rho = 0.95$, $\delta = 0$ and $\bar{s} = 0.25$, at the beginning of each period with a status-quo x , last period optimal interest rate i^* and fresh draw of $r = \{\bar{i}^*, i^{P1}, \dots, i^{PN}, i^C\}'$ we first need to derive C 's proposal y . This will be given as a solution to the

$$\max_{y \in Y} \mathbb{E} [-(p(x, y) - \bar{i}^*)^2 | i^*, i^C] \quad (\text{A1})$$

optimization problem where $p(x, y)$ is policy adopted given proposal y and status-quo x . The optimization problem can be rewritten as

$$\max_{y \in Y} p_a \mathbb{E} [-(y - \bar{i}^*)^2 | i^*, i^C, a] + (1 - p_a) \mathbb{E} [-(x - \bar{i}^*)^2 | i^*, i^C, \hat{a}] \quad (\text{A2})$$

where a is event of y being accepted, \hat{a} is event of y being rejected and p_a is probability of the a event.

Next we will need to calculate probability of offer y being accepted against status-quo x , p_a . In order to do so, chairman C knows, and we show below, that the remaining players will vote for y if and only if their signal is above (or below but this case is symmetric) certain cut-off we denote here by k . Other relevant information C has is her own signal i^C and previous optimal interest rate i^* and hence we need to calculate probability of at least $\frac{N}{2}$ or more P members voting for y given i^C and i^* . Probability of, say, first N' members voting for y is equal to $P(\#|i^P \geq k| = N', \#|i^P < k| = N - N' | i^*, i^C)$ and is straightforward to calculate as we know the distribution of the random vector $\{i^{P1}, \dots, i^{PN}\}'$ and can always transform it into a problem of calculating $\mathbb{P}(\#|i^P \leq k| = N | i^*, i^C)$ by multiplying the whole problem (that is the mean and variance-covariance matrix) by $\{-1, \dots, -1, 1, \dots, 1\}'$ where there is N' negative ones and

$N - N'$ positive ones. The probability can then be calculated using standard cumulative distribution function of multivariate normal. Denoting the probability of first N' members accepting by $\mathbb{P}_{N'}$, probability of accepting becomes $\sum_{i=N/2}^N \mathbb{P}_i \binom{N}{i}$.

Key computational problem in simulating the democratic model is computing expected value of \bar{i}^* given C 's signal i^C , i^* and the event of y being accepted as the event of accepting y means that signals i^P of $\frac{N}{2}$ or more P members must have been above (or below) certain threshold k . There are two results we use to make the computation simpler that are straightforward to prove. First for random variable X and two mutually exclusive and exhaustive events A and B we have

$$\mathbb{E}[X] = \mathbb{E}[X|A]\mathbb{P}(A) + \mathbb{E}[X|B]\mathbb{P}(B)$$

and similar result for variance states that

$$\begin{aligned} \text{var}(X) = & \text{var}(X|A)\mathbb{P}(A) + \text{var}(X|B)\mathbb{P}(B) \\ & + (\mathbb{E}[X|A] - \mathbb{E}[X])^2\mathbb{P}(A) + (\mathbb{E}[X|B] - \mathbb{E}[X])^2\mathbb{P}(B) \end{aligned}$$

which greatly simplifies calculation of some of the expressions below.

Nevertheless the key problem remains as we need to calculate expectation of the form $\mathbb{E}[\bar{i}^* | i^*, i^C, \#|i^P \geq k] = N'$, $\#|i^P < k] = N - N'$. First step is simple and amounts to calculating distribution of $\{\bar{i}^*, i^{P1}, \dots, i^{PN}\}'$ given i^* and i^C which is $N(\mu, \Sigma)$ with each element of μ equal to $\frac{\rho i^* \sigma_C^2 + i^C \sigma_u^2}{\sigma_u^2 + \sigma_C^2}$, and Σ being matrix with vector $\{\sigma', \sigma' + \sigma_P^2, \dots, \sigma' + \sigma_P^2\}'$ on the main diagonal and $\sigma' = \frac{\sigma_u^2 \sigma_C^2}{\sigma_u^2 + \sigma_C^2}$ off the main diagonal. We then convert the problem into one of finding $\mathbb{E}[\bar{i}^* | \#|i^P \geq k] = N'$ using the technique just explained for calculation of p_a . This leaves us with multivariate truncated normal random vector with known mean and variance. To calculate the expectation we used results in Tallis (1961) and Lee (1979) and wrote our own MATLAB function which calculates the expectation. We checked its correctness using R-software 'tmvtnorm' package (see Wilhelm 2010).

With those results, we can expand the maximand in (A2) and use the rules for conditional expectations and variance from above, then we determine the value of the objective function for each $y \in Y$ using the function for expectation of truncated multivariate normal finally determining solution to C 's optimization problem and hence her proposal.

With C 's proposal y determined we can determine voting behaviour of the remaining P committee members. For each member j we use the voting rule (2) from the text adopted to the

democratic model

$$\mathbb{E} [-(y - \bar{i}^*)^2 | i^*, i^j] \geq \mathbb{E} [-(x - \bar{i}^*)^2 | i^*, i^j] \quad (\text{A3})$$

which rewrites as

$$x^2 - y^2 \geq 2(y - x)\mathbb{E}[\bar{i}^* | i^*, i^j] \quad (\text{A4})$$

with $\mathbb{E}[\bar{i}^* | i^*, i^j] = \frac{\rho i^* \sigma_j^2 + i^j \sigma_u^2}{\sigma_u^2 + \sigma_j^2}$. This result also proves that each P member votes for y if and only if his signal is above (or below depending on the position of status-quo) certain cut-off. With the voting pattern determined we can calculate the *skew* variable and proceed to the next period.

In the consensual model with $\rho = 0.95$, $\delta = 0$ and $\bar{s} = 0.25$, at the beginning of each period with a status-quo x , last period optimal interest rate i^* and fresh draw of $r = \{\bar{i}^*, i^{P1}, \dots, i^{PN}, i^C\}$ proposal y will be policy most preferred by C . This is equal to policy in Y that is closest to C 's expectation of \bar{i}^* given her signal i^C and previous optimal policy rate i^* . This expectation is equal to $\mathbb{E}[\bar{i}^* | i^*, i^C] = \frac{\rho i^* \sigma_C^2 + i^C \sigma_u^2}{\sigma_u^2 + \sigma_C^2}$.

Next we need to determine behaviour of P committee members. In the consensual model each P member j will vote based on the voting rule (2) using his information about previous optimal interest rate i^* , his private signal i^j and information embedded in C 's proposal y , hence the voting rule rewrites as

$$x^2 - y^2 \geq 2(y - x)\mathbb{E}[\bar{i}^* | i^*, i^j, y] \quad (\text{A5}).$$

It is easy to confirm that information embedded in C 's proposal is equal to an event of $i^C \in \langle i_l^C, i_u^C \rangle$ where lower bound of the interval is $i_l^C = \frac{1}{\sigma_u^2} [(y - \frac{\bar{s}}{2})(\sigma_u^2 + \sigma_C^2) - \sigma_C^2 \rho i^*]$ and upper bound of the interval is $i_u^C = \frac{1}{\sigma_u^2} [(y + \frac{\bar{s}}{2})(\sigma_u^2 + \sigma_C^2) - \sigma_C^2 \rho i^*]$. Calculation of $\mathbb{E}[\bar{i}^* | i^*, i^j, i^C \in \langle i_l^C, i_u^C \rangle]$ is then easy using law of iterated expectations which allows us to rewrite the expression to $\mathbb{E}[\mathbb{E}[\bar{i}^* | i^*, i^j, i^C] | i^*, i^j, i^C \in \langle i_l^C, i_u^C \rangle]$. The inner expectations are equal to $\frac{\rho i^* \sigma_j^2 \sigma_C^2 + i^j \sigma_u^2 \sigma_C^2 + i^C \sigma_u^2 \sigma_j^2}{\sigma_u^2 \sigma_j^2 + \sigma_u^2 \sigma_C^2 + \sigma_C^2 \sigma_j^2}$. Moreover we know that distribution of i^C given i^* and i^j is normal with mean $\frac{\rho i^* \sigma_j^2 + i^j \sigma_u^2}{\sigma_u^2 + \sigma_j^2}$ and variance $\frac{\sigma_u^2 \sigma_j^2}{\sigma_u^2 + \sigma_j^2} + \sigma_C^2$. Last result we use to calculate the expectations is that for random variable x_1 distributed according to $N(\mu, \sigma^2)$, conditional expectation of x_1 given that $x_1 \in \langle a_l, a_u \rangle$ is given by $\mathbb{E}[x_1 | x_1 \in \langle a_l, a_u \rangle] = \mu + \sigma \frac{\phi(\frac{a_l - \mu}{\sigma}) - \phi(\frac{a_u - \mu}{\sigma})}{\Phi(\frac{a_u - \mu}{\sigma}) - \Phi(\frac{a_l - \mu}{\sigma})}$ where $\phi(\cdot)$ and $\Phi(\cdot)$ are probability density and cumulative distribution functions of univariate standard normal

distribution respectively. With the voting pattern determined we can calculate the *skew* variable and proceed to the next period.

In the opportunistic model with $\rho = 0.95$, $\delta = 0$, $\bar{s} = 0.25$ chairman C knows the most preferred policies of all the committee members. For each player j this policy will be policy in Y closest to j 's expectation of \bar{i}^* given i^* and i^j , i.e. closest to $\mathbb{E}[\bar{i}^*|i^*, i^j] = \frac{\rho i^* \sigma_j^2 + i^j \sigma_u^2}{\sigma_u^2 + \sigma_j^2}$. At the beginning of each period with status-quo x and the last period optimal interest rate i^* , given fresh drawn of $r = \{\bar{i}^*, i^{P1}, \dots, i^{PN}, i^C\}'$, we will then have vector of most preferred policies $\{p_1^*, \dots, p_{N+1}^*\}$ which we order so that $p_j^* \leq p_{j+1}^*$ for $j \in \{1, \dots, N\}$ where we denote policy most preferred by median member by $p_m^* = p_{N/2+1}^*$

In the opportunistic model C 's proposal will be policy which receives super-majority of at least $\frac{N}{2} + 2$ members. It is easy to see that this will be policy in the (x, p_m^*) interval (where the order is reversed if status-quo x is larger than p_m^*) that is closest to p_m^* if such policy exists. Otherwise, the proposal will be equal to the status-quo x .

Next we need to calculate the *skew* variable. For this we again use the voting rule (2) along with an assumption that player j does not extract any information content from proposal y and votes for y as opposed to voting for status-quo x if and only if

$$x^2 - y^2 \geq 2(x - y)\mathbb{E}[\bar{i}^*|i^*, i^j] \quad (\text{A6})$$

with $\mathbb{E}[\bar{i}^*|i^*, i^j] = \frac{\rho i^* \sigma_j^2 + i^j \sigma_u^2}{\sigma_u^2 + \sigma_j^2}$. By construction C 's proposal is always accepted with number of votes for y being at least $\frac{N}{2} + 2$. With the voting pattern and hence *skew* determined we move to the next period.

Finally in the intertemporal democratic model with $\bar{s} = 0.25$, $\rho = 0$ and $\delta = 0.95$ previous period optimal interest rate i^* plays no role and hence the only relevant information is current status-quo x . We again start each period of the simulation by drawing fresh values for $r = \{\bar{i}^*, i^{P1}, \dots, i^{PN}, i^C\}'$. Next we need to determine C 's proposal. This will be again solution to

$$\max_{y \in \mathbb{X}} \mathbb{E} \left[-(p(x, y) - \bar{i}^*)^2 + \delta U_C(p(x, y), \bar{i}^C) | i^C \right] \quad (\text{A7})$$

optimization problem where the $U_C(\cdot)$ function is continuation value function of a game starting with status-quo $p(x, y)$ and C 's signal \bar{i}^C . The expression can again be rewritten as

$$\max_{y \in \mathbb{X}} \left[p_a \mathbb{E}[-(y - \bar{i}^*)^2 | i^C, a] + (1 - p_a) \mathbb{E}[-(x - \bar{i}^*)^2 | i^C, \hat{a}] \right] + \delta p_a V_C(y) + \delta (1 - p_a) V_C(x) \quad (\text{A8})$$

where $V_C(x) = \int U_C(x, z) f(z) dz$ with $f(z)$ probability distribution function of univariate normal distribution with mean zero and variance equal to $\sigma_u^2 + \sigma_C^2$. With $V_C(\cdot)$ known (we explain its estimation below) we proceed similarly as in the democratic model calculating probability of y being accepted and expected values in the maximand. Distribution of the random variables $\{\bar{i}^*, i^{P1}, \dots, i^{PN}\}$ given i^C is again $N(\mu, \Sigma)$ with each element of μ equal to $\frac{i^C \sigma_u^2}{\sigma_u^2 + \sigma_C^2}$, and Σ being matrix with vector $\{\sigma', \sigma' + \sigma_P^2, \dots, \sigma' + \sigma_P^2\}'$ on the main diagonal and $\sigma' = \frac{\sigma_u^2 \sigma_C^2}{\sigma_u^2 + \sigma_C^2}$ off the main diagonal.

Voting behaviour of P member j given status-quo x , proposal y and signal i^j is again given by the voting rule (2) which for intertemporal democratic model becomes

$$\mathbb{E}[-(y - \bar{i}^*)^2 + \delta U_P(y, \bar{i}^j) | i^j] \geq \mathbb{E}[-(x - \bar{i}^*)^2 + \delta U_P(x, \bar{i}^j) | i^j] \quad (\text{A9})$$

where the $U_P(\cdot)$ function is continuation value function of a P member from a game starting with given status-quo and signal. Note that this function is equal for all P players. This condition can be rewritten as

$$x^2 - y^2 + \delta(V_P(y) - V_P(x)) \geq 2(y - x) \mathbb{E}[\bar{i}^* | i^j] \quad (\text{A10})$$

with $\mathbb{E}[\bar{i}^* | i^j] = \frac{i^j \sigma_u^2}{\sigma_u^2 + \sigma_j^2}$ and $V_P(x) = \int U_P(x, z) f(z) dz$ with $f(z)$ probability distribution function of univariate normal distribution with mean zero and variance equal to $\sigma_u^2 + \sigma_P^2$. With the voting pattern determined we can calculate the *skew* variable and proceed to the next period.

It remains to explain how we determine the continuation value functions. Prior to running the simulations, we estimate the $V_C(\cdot)$ and $V_P(\cdot)$ functions by standard value function iteration. We start with $V_{C,0}(\cdot) = 0$ and $V_{P,0}(\cdot) = 0$ and determine both functions $V_{C,s}(\cdot)$ and $V_{P,s}(\cdot)$ in a general step s as follows.

For $V_{C,s}(\cdot)$ we use numerical integration via standard Gaussian quadrature method using the ‘compecon’ toolbox described in Miranda and Fackler (2002). To determine $V_{C,s}(x)$ for a specific value of x we determine set of nodes for C 's signals $\{i^1, \dots, i^H\}$ (using $H = 9$ in practice) and for each signal $i^h \in \{i^1, \dots, i^H\}$ calculate

$$U_{C,s}(x, i^h) = \max_{y \in \mathbb{X}} \left[p_a \mathbb{E}[-(y - \bar{i}^*)^2 | i^h, a] + (1 - p_a) \mathbb{E}[-(x - \bar{i}^*)^2 | i^h, \hat{a}] \right] + \delta p_a V_{C,s-1}(y) + \delta (1 - p_a) V_{C,s-1}(x) \quad (\text{A11})$$

using the approach described above. The cut-off values for calculation of the probability of acceptance are derived from the voting rule which uses $V_{P,s-1}(\cdot)$ function.

For $V_{P,s}(\cdot)$ we use the same numerical integration approach generating set of P 's signals and numerically integrating $V_{P,s}(x) = \int U_{P,s}(x, z) f(z) dz$. The only complication is that we need to determine the $U_{P,s}(\cdot)$ function. For specific status-quo x and signal i^j of P player j , $U_{P,s}(x, i^j)$ gives continuation value from the game starting with x and i^j and hence can be written as

$$U_{P,s}(x, i^j) = \mathbb{E} [-(p - \bar{i}^*)^2 + \delta U_{P,s-1}(p, \bar{i}^j) | i^j] \quad (\text{A12})$$

but the expectation operator hides considerable complexity. First, j does not know C 's signal and hence her proposal. Second, j does not know whether the proposal will be accepted or not and third, j does not know next period signal. Reconciling the third source of uncertainty is straightforward and the whole expression can be rewritten as

$$U_{P,s}(x, i^j) = \mathbb{E} [-(p - \bar{i}^*)^2 + \delta V_{P,s-1}(p) | i^j] \quad (\text{A13})$$

with only the first two sources of uncertainty remaining.

To resolve those we need to take expectations over the C 's signal which will determine her proposal as well. Expanding the expectations operator thus gives

$$U_{P,s}(x, i^j) = \int \left[p_a(z) [\mathbb{E} [-(y(z) - \bar{i}^*)^2 | i^j, z, a] + \delta V_{P,s-1}(y(z))] + (1 - p_a(z)) [\mathbb{E} [-(x - \bar{i}^*)^2 | i^j, z, \hat{a}] + \delta V_{P,s-1}(x)] \right] f(z) dz \quad (\text{A14})$$

where the variable of integration is C 's signal, $y(z)$ is C 's proposal given her signal, $p_a(z)$ is probability of this proposal being accepted and $f(z)$ is probability distribution function of C 's signal.

Hence in order to get $V_{P,s}(\cdot)$ we need to integrate twice, once over distribution of j 's signal (which will be normal with mean zero and variance $\sigma_u^2 + \sigma_p^2$) and once over distribution of C 's signal (which for given value of i^j will be normal with mean equal to $\frac{i^j \sigma_u^2}{\sigma_u^2 + \sigma_p^2}$ and variance equal to $\frac{\sigma_u^2 \sigma_p^2}{\sigma_u^2 + \sigma_p^2} + \sigma_C^2$). Integrating numerically then amounts to generating grid of discrete nodes in \mathbb{R}^2 with one dimension for j 's signals and nodes $\{i^1, \dots, i^M\}$ and second dimension for C 's signal and nodes $\{i^1, \dots, i^H\}$ (again we use $H = M = 9$ in practice).

For each node in \mathbb{R}^2 consisting of $\{i^m, i^h\}$ we calculate

$$\begin{aligned} & p_a(i^h)[\mathbb{E}[-(y(i^h) - \bar{i}^*)^2 | i^m, i^h, a] + \delta V_{P,s-1}(y(i^h))] \\ & + (1 - p_a(i^h))[\mathbb{E}[-(x - \bar{i}^*)^2 | i^m, i^h, \hat{a}] + \delta V_{P,s-1}(x)] \end{aligned} \quad (\text{A15})$$

which then allows us to calculate $V_{P,s}(\cdot)$. To calculate the expression we first calculate C 's proposal $y(i^h)$. Given the proposal we can calculate probability of the proposal being accepted (with j taking into account his own voting behaviour) and finally the remaining expectations given acceptance or rejection. In the whole expression j will condition on information embedded in $\{i^m, i^h\}$ and hence an appropriate conditional distribution of the remaining random variables in the model $\{\bar{i}^*, i^{P1}, \dots, i^{PN-1}\}$ is multivariate normal $N(\mu, \Sigma)$ with each element of μ equal to $\frac{\sigma_u^2(\sigma_C^2 i^m + \sigma_P^2 i^h)}{\sigma_u^2(\sigma_C^2 + \sigma_P^2) + \sigma_C^2 \sigma_P^2}$ and Σ being matrix with vector $\{\sigma', \sigma' + \sigma_P^2, \dots, \sigma' + \sigma_P^2\}'$ on the main diagonal and $\sigma' = \frac{\sigma_u^2 \sigma_C^2 \sigma_P^2}{\sigma_u^2(\sigma_C^2 + \sigma_P^2) + \sigma_C^2 \sigma_P^2}$ off the main diagonal.

We iterate on s until $\max\{\|V_{P,s} - V_{P,s-1}\|, \|V_{C,s} - V_{C,s-1}\|\} \geq 0.001$ where $\|\cdot\|$ is usual sup norm. We experienced no problems with convergence with typical s needed was around 70 iterations.

A2 Data

Voting records

Voting records from the following central banks has been collected (the start and end data of the sample in brackets): the Czech Republic (1998:1-2008:12), the United Kingdom (1997:6-2009:2), Hungary (2005:10-2009:2), Poland (2000:2-2008:12) and Sweden (1999:1-2009:2). Typically, voting data are available at a monthly frequency. The data are publicly available at the websites of central banks.

As regards the Czech Republic, the 1998:1-2000:6 voting results were available only in the transcripts that are published with a six years delay. Therefore, the baseline estimates for this country are based on the data from 2000:7 onwards. In addition, the baseline estimates for the Czech Republic are restricted until 2006:7 in the specification with the financial market expectations. The reason is that from this period the voting record was released only about 3 hours after the monetary policy decision was announced. The monetary policy decision was typically announced around 1PM and the voting ratio was released at around 3.30PM at the press conference. While in principle the interbank rates could be collected at say 2PM and therefore more recent data could have been used as well, but it has to be emphasized that the interbank market was not very liquid during financial crisis. In light of this fact, we restrict the data for the Czech Republic to the period until 2006:7.

U.S. Fed to be added.

Interbank rates

The interbank rates are collected to grasp the financial market expectations. The source of data is Datastream. Specifically, PRIBOR rates for the Czech Republic, BUBOR rates for Hungary, WIBOR rates for Poland, STIBOR rates for Sweden and LIBOR rates for the U.K. for the following maturities: 1 month, 3 months and 12 months.

A3 Central Banks' Voting Record Release Schedules

Czech National Bank

The Bank Board meets on Thursdays.⁶ A press conference with a presentation containing the voting ratio (without the names) takes place the same day in the early afternoon.

Until 8/2006, the voting ratio was not published on the press conference.

The minutes are released next Fridays (+8 days), containing voting ratio, from 1/2008 also with the names explicitly.

Until 4/2005, minutes were released on Tuesdays two weeks after the meetings (+12 days).

Bank of England

The Monetary Policy Committee decides during a two-day meeting, taking place on Wednesdays and Thursdays. A press release of the decision follows on Thursday noon.

The minutes are released in the fortnight, on Wednesdays after two weeks (+13 days), containing a voting record with names.

Magyar Nemzeti Bank

The Monetary Council meets on Mondays. A press release of the decision follows on Monday at 15:00.

The minutes are released in 2-4 weeks after the decision, but usually on Wednesdays. These contain a detailed voting record with names.

National Bank of Poland

The Monetary Policy Council decides during a two-day meeting, taking place on Tuesdays and Wednesdays. A press release of the decision follows on Wednesday.

The minutes are released on Thursdays in the week before the next meeting of the MPC, which means after 3-4 weeks after the respective decision.

The MPC meeting minutes do not contain the voting records. The voting records are published with a lag only in the quarterly Inflation Reports. If the repo rate was changed, the voting record is first published in the Court and Economic Gazette of the Ministry of Justice and only after that in the inflation report. Voting records in the Court and Economic Gazette have to be published not sooner than 6 weeks and no later than 12 weeks after voting took place.

Sveriges Riksbank

The Executive Board meets on Mondays or Wednesdays. A press release of the decision follows the same day.

The minutes are released approximately after two weeks (+14, occasionally +15 days), containing a detailed voting record with names.

U.S. Fed to be added.

⁶ There are some exceptions to organization of the monetary policy decision making process for all central banks typically because of national holidays. For example in the case of the Czech National Bank, the board meets on Thursday. In exceptional cases, it may meet on Wednesday instead of Thursday because of holidays. From 4/2005, minutes are published 8 days after the meeting. In case of holidays, minutes can be published after more than 8 days.