

# Central Bank Reputation, Cheap Talk and Transparency as Substitutes for Commitment: Experimental Evidence\*

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**Abstract:** We implement a repeated version of the Barro-Gordon monetary policy game in the laboratory and ask whether reputation serves as a substitute for commitment, enabling the central bank to achieve the efficient Ramsey equilibrium and avoid the inefficient, time-inconsistent one-shot Nash equilibrium. We find that reputation is a poor substitute for commitment. We then explore whether central bank cheap talk, policy transparency, both cheap talk and policy transparency or economic transparency yield improvements in the direction of the Ramsey equilibrium under the discretionary policy regime. Our findings suggest that these mechanisms have only small or transitory effects on welfare. Surprisingly, the real effects of supply shocks are better mitigated by a commitment regime than by any discretionary policy. Thus, we find that there is no trade-off between flexibility and credibility.

**Keywords:** Monetary Policy, Time Inconsistency, Repeated Games, Central Banking, Commitment, Discretion, Cheap Talk, Transparency, Experimental Economics.

**JEL Codes:** C73, C92, D83, E52, E58.

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## 1. Introduction

Should central bankers commit to a consistent monetary policy or should they be afforded discretion to alter monetary policy depending on current circumstances? This question, as first posed by Kydland and Prescott (1977) and elaborated upon by Barro and Gordon (1983ab) continues to be debated in discussions of monetary policy design. In current terms, the time inconsistency problem arises between commitment to a forward guidance policy regarding future interest rates and a discretionary response of setting interest rates in response to changes in inflation.<sup>1</sup> On the one hand, the ability to use monetary policy to flexibly respond to various economic shocks as they arise is the main argument in favor of discretionary policy (e.g., Blinder (1999)). On the other hand, it is well known that the ability to commit to a consistent policy course of action or rule can yield welfare improvements over a pure discretionary policy regime through the effect that the commitment policy has on private sector expectations (e.g., Taylor (1999)). The latter argument hinges on the reputation that central bankers can achieve from consistently applying a low inflation monetary policy and thus envisions a repeated game setting between the policy maker and the private sector.

In this paper we implement a version of the repeated policy game due to Barro and Gordon (1983a) in the laboratory with paid human subjects playing the role of the central banker and the private sector. We have several aims in mind. First, we wish to explore whether reputational considerations can serve as a substitute for commitment in a repeated game setting where central bankers lack a commitment device and are free to alter monetary policy each period conditioning on realizations of economic shocks. We compare this flexible, discretionary regime with a commitment regime where central bankers have the ability to commit to a course for monetary policy in advance of the formation of private sector expectations, but no flexibility for stabilizing the economy. Our experimental findings from these two regimes reveal that reputation is indeed a poor substitute for commitment in that inflation is higher and welfare is lower in the discretionary environment as compared with the commitment regime.

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<sup>1</sup> See Filardo and Hofmann (2014) for a discussion of time inconsistency with respect to forward guidance.

However, our baseline model lacks a number of mechanisms (besides reputational considerations) that central bankers, primarily in OECD countries, have come to employ in an effort to further establish credibility in the discretionary policy regimes in which they operate. For instance, since the introduction of inflation targeting in the 1990s, these central bankers have become considerably less secretive about policy goals and policy measures, communicating ever more frequently with the public, being transparent about their monetary policy frameworks, targets, and instruments and even sharing information about economic fundamentals (Vayid 2013). This trend accelerated following the 2007-08 financial crises; among the unconventional monetary policies resulting from the crisis was *forward guidance*, wherein the central bank explains how the future policy path will change with changes in economic conditions. These new mechanisms may have helped these central bankers to establish or preserve credibility, while continuing to operate in a discretionary policy, dynamic repeated-game environment. Thus, a second goal of this paper is to evaluate the efficacy of some of these newer central bank mechanisms in our discretionary policy regime setting so as to better understand the role they may play in enhancing welfare. In particular, we explore the role of non-binding central bank communication or “cheap talk” about policy targets as well as transparency about policy actions, both cheap talk and policy transparency, and finally economic transparency as mechanisms for overcoming the inflationary bias under discretionary policy.<sup>2</sup> Since many of these mechanisms have also been studied theoretically in the context of Barro-Gordon type monetary policy game set-ups (see, Geraats (2002, 2014) for surveys), the environment we study is an appropriate one for the analysis of the effectiveness of these mechanisms.

We find that of the various mechanisms we study, cheap talk alone results in some welfare improvement relative to the baseline discretionary environment, but the benefits of cheap talk appear to decline with experience. In the end, we conclude that none of the various mechanisms we examine comes close to

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<sup>2</sup> We do not study the case of forward guidance, which we view as a close cousin to our commitment and policy transparency regimes.

achieving the welfare levels of the commitment regime. These findings suggest that there may well be *real* welfare-reducing consequences to discretionary monetary policy.

We adopt an experimental approach as it provides us with the control necessary to properly identify whether different policy regimes, e.g., commitment versus various discretionary regimes, matter for policy choices, private sector expectations and welfare in a manner that is not possible using non-experimental field data, because in the field, changes in policy regimes are often a consequence of insufficient management of expectations and, thus, are endogenous.<sup>3</sup> Additionally, the indefinitely repeated environments we study admit multiple equilibria. As Lucas (1986, p. 237) has argued, in such settings “it is hard to see what can advance the discussion short of assembling a collection of people, putting them in the situation of interest and seeing what they do.”

Our experiment makes use of student subjects to play the role of both central bankers and private sector agents. While ideally, we would have real central bankers make monetary policy choices in our experiment, there are good reasons to think that our experimental findings nevertheless remain externally valid and relevant to the discussion of actual central bank practice. As Cornand and Heinemann (2014) emphasize, while quantitative experimental findings might be specific to the laboratory environment and to chosen parameter values (e.g., the discount rate), the *qualitative* results from comparing treatments with each other and with equilibria are likely to be robust and externally valid.

The rest of the paper is organized as follows. Section 2 reviews the related literature. Section 3 outlines the one-shot and repeated Barro-Gordon model that we implement in the laboratory. Section 4 describes our experimental design and hypotheses and Section 5 reports on the main findings from our experiment. Finally, Section 6 concludes.

## **2. Related Literature**

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<sup>3</sup> Another advantage of conducting a laboratory experiment is that we are able to implement a commitment regime as a theoretical benchmark, while in more natural (i.e., non-laboratory) settings such commitment devices may have credibility problems.

Three prior experiments have been conducted that are related to this paper. Van Huyck et al. (1995, 2001) implement a “peasant-dictator” game in the laboratory. In this two-player game, players are randomly paired, with one being designated as the peasant and the other the dictator. Pairs interact in a repeated game that continues from one round to the next with probability  $5/6$  and, thus, has an indefinite time horizon. Peasants decide on how much of their endowment of beans to eat or plant (invest) yielding new beans in the next period (if there is a next period). Dictators tax production and can either commit to a tax rate in advance of the peasant’s investment (commitment regime) or decide on a tax ex-post, after investments have been made but prior to their realization (discretionary regime). The authors vary the endowments of the peasants and the interest rate earned on investments.<sup>4</sup> They report that reputation is an imperfect substitute for commitment and that efficiency under discretion is positively associated with the interest rate earned on investment.

Arifovic and Sargent (2003) implement an experimental version of the Kydland-Prescott model using a design similar to our own. In their study, subjects are divided up between policymakers and private sector forecasters with one policymaker and 3-5 private sector forecasters in each repeated game. Private sector forecasters move first: their objective is to correctly forecast next period’s inflation. These inflation expectations then enter into a Phillips curve relation that determines the extent to which unemployment departs from its natural rate. The central bank moves second. It has noisy control over the actual inflation rate and seeks to minimize its expected loss from the equal weighted sum of the square of the unemployment and inflation rates. Arifovic and Sargent study only a discretionary regime and their treatment variables primarily consist of changes in the variance of shocks to the Phillips curve and inflation setting policy rule. By contrast with Van Huyck et al. they report that subjects do learn to coordinate on the first best Ramsey equilibrium consistent with a commitment regime, despite operating in a pure discretionary environment – that is they find that reputation does work as a substitute for commitment. In particular, they report that in

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<sup>4</sup> They report that while they tried a treatment where the dictator made cheap talk announcements of intended tax rates (as we do here) they were dissatisfied with the results of this treatment and dropped it from their analysis.

three fourths of their sessions, policymakers eventually learn the Ramsey zero-inflation policy and stay with that policy for some time, though in several of the economies they report some “backsliding” toward the less efficient Nash equilibrium associated with one-shot pure discretionary regime after the Ramsey equilibrium had been achieved and sustained for some time.

Arifovic (2014) studies a version of the Kydland-Prescott model found in Arifovic et al. (2010) where the central bank makes cheap talk announcements about inflation in advance of private sector expectation formation and the private sector consists either of non-believers, or in a second treatment, non-believers and believers. The only experimental (human) subjects in this study are the non-believers. Both the central bank and the believer private sector agents are automated robot players who either learn over time in an evolutionary manner (the central bank) or blindly follow the central bank’s pronouncements (the private sector believers). Arifovic’s main finding is that with non-believers (human subjects) only or non-believers and believers (both human and robot private sector players) actual inflation levels lie below the one-shot Nash equilibrium prediction, though inflation is more volatile in the non-believer, humans-only, treatment.

Our experiment complements and builds upon these earlier experimental studies but differs from them in several respects. First, the Barro-Gordon model that we implement in the laboratory differs from the tax policy focus of the Van Huyck et al. study and differs in certain timing respects from the Kydland and Prescott model of time inconsistent policy studied by Arifovic and Sargent (2003) and Arifovic (2014). For example, in our model, which follows the Barro and Gordon timing, the central banker always learns inflation forecasts *in advance* of setting monetary policy. By contrast, the Arifovic-Sargent study follows the Kydland-Prescott timing, where private forecasts are set in advance and affect real outcomes but these expectations are only known to policymakers ex-post. The latter assumption means that the central bank cannot purposefully create surprise inflation (inflation in excess of the private sector’s expectations), and this timing difference may well explain why Arifovic and Sargent found sustained periods of coordination around the Ramsey solution. Also differently from Arifovic and Sargent, both policymakers and forecasters in our study are fully informed of the model economy and subjects can play both roles over the course of

an experimental session. By contrast with Arifovic (2014), we have no robot (or automated) players. Similar to Van Huyck et al., we study the case of both commitment and discretion. However we go beyond these two policy regimes and examine choices under the discretionary regime when 1) the policymaker can engage in pre-play cheap talk about intended policy choices as in Arifovic (2014) but with real human subjects making those announcements; 2) policy choices are made transparent to the private sector at the end of each period; 3) there is both pre-play cheap talk and ex-post monetary policy transparency and 4) there is a regime of economic transparency where the private sector is informed about an economically relevant supply shock prior to forming their expectations (the policymaker is always informed of this shock in advance of setting policy). Thus our experiment goes beyond a comparison of repeated discretionary decision-making versus commitment and begins the important work of evaluating a number of non-reputation-based mechanisms by which it is thought that central bankers might overcome the inflation bias that is possible in the repeated but discretionary environments in which they operate.

While we study cheap talk and policy transparency in the context of the repeated Barro-Gordon model, other studies have explored the role of such policies in other frameworks. For instance, cheap talk has been explored by experimentalists as a mechanism for solving equilibrium coordination problems (see Crawford (1998) for a survey). Duffy and Feltovich (2006) report on experiments where the truthfulness of prior cheap talk messages (the extent of lying) can be evaluated by the receivers of those messages as in our policy transparency treatment. However, that study and most other studies of pre-play communication have not been conducted in indefinitely repeated games where communication might help solve coordination problems arising from folk-theorem results. An exception is Camera et al. (2011) who study indefinitely repeated prisoner's dilemma games where free-form or structured pre-play communication is allowed at various intervals in the supergame. Similar to our findings, Camera et al. (2011) report that such communication does not help subjects achieve the most efficient equilibrium possible as subjects use communication for both benevolent and deceptive purposes. Kryvstov and Petersen (2013) report on experiments in a New Keynesian framework where they find that central bank announcements (cheap talk)

about future interest rates are more destabilizing relative to a regime without such announcements. Cornand and M'baye (2018) also report on monetary policy experiments in a New Keynesian environment. They find that announcing an inflation target (policy transparency) does not lead to any welfare improvement relative to standard discretionary policy when the central bank only cares about inflation stabilization, though there are modest improvements if the central bank cares about both inflation and output stabilization. We view these results as complementary to our own findings.

### 3. The Model

The model economy we implement in the laboratory is a version of that used by Barro and Gordon (1983ab). We begin with the static version before moving to the repeated (dynamic) version. Within the static environment we consider first the case of discretion and then the case of commitment.

#### 3.1 Static model

The unemployment rate,  $u$ , is determined according to a Lucas-style aggregate supply function

$$u = u_n - c(\pi - \pi^e) + w,$$

where  $u_n$  denotes the non-accelerating inflation rate of unemployment (NAIRU),  $\pi$  denotes the time  $t$  inflation rate,  $\pi^e$  denotes private sector expectations of the inflation rate at time  $t$ ,  $c$  is a constant and  $w$  is a mean zero random supply shock. This supply function can be derived from the expectations-augmented Phillips curve view of the inflation-output tradeoff and implies that output and unemployment deviate from their natural rates only in response to unanticipated inflation. The central bank's monetary policy consists of its choice of  $m$ , denoting the rate of growth of the money supply, which determines the actual inflation rate according to:

$$\pi = m + v,$$



where  $v$  is a mean zero policy disturbance term (e.g., due to changes in the velocity of money or an unanticipated demand shock). The model is closed under the assumption that the private sector has rational expectations, so that  $\pi^e = E(\pi)$  and that the central bank seeks to minimize the time  $t$  loss function

$$EL = E(b(\pi - \pi^*)^2 + (u - u^*)^2),$$

where  $EL$  denotes the expected loss,  $\pi^*$  is the central bank's desired inflation rate and  $u^* < u_n$  denotes the central bank's desired unemployment rate which is assumed to be smaller than the NAIRU.

In the discretionary regime, the private sector moves first forming their expectations for inflation,  $\pi^e$ . The central bank is informed of these expectations and takes them as given when minimizing  $EL$  subject to the expressions for  $u$  and  $\pi$ . The central bank's reaction function, given the private sector's expectations for inflation,  $\pi^e$ , is given by:

$$m = \frac{b\pi^* + c(u_n - u^* + w) + c^2\pi^e}{b + c^2}. \quad (1)$$

The private sector is assumed to have rational expectations about inflation and we distinguish whether or not the private sector is informed about supply shocks when forming those expectations. If the private sector cannot observe supply shocks, we have that  $\pi^e = E(\pi) = E(m) = \frac{b\pi^* + c(u_n - u^*) + c^2\pi^e}{b + c^2}$ , or that  $\pi^e = \pi^* + \frac{c}{b}(u_n - u^*)$ , which implies that the money supply in the Nash equilibrium is:

$$m^{NE} = \pi^* + \frac{c}{b}(u_n - u^*) + \frac{c}{b + c^2}w = \pi^{NE} + \frac{c}{b + c^2}w.$$

Thus the policy choice in the Nash equilibrium (NE) of the one-shot discretionary environment involves an average inflation rate,  $\pi^{NE}$ , that is greater than the desired level,  $\pi^*$ , by the amount  $\frac{c}{b}(u_n - u^*)$ . This difference,  $\pi^{NE} - \pi^*$ , is known as the *inflation bias* of discretionary policy. The third and final term,  $\frac{c}{b + c^2}w$ , reflects the central bank's incentive for stabilizing employment by adjusting the money supply to supply shocks,  $w$ .

If the central bank releases its information about supply shocks to the private sector before the formation of expectations, then  $\pi^e = E(\pi|w) = E(m|w)$ , which implies  $\pi^e = \pi^* + \frac{c}{b}(u_n - u^* + w)$  and

$$m^{ET} = \pi^* + \frac{c}{b}(u_n - u^* + w) = \pi^{NE} + \frac{c}{b}w.$$

We refer to this regime as one of “economic transparency” (ET) following Geraats (2002, p. F540), who writes that “economic transparency focuses on the [openness to the private sector about the] economic information that is used for monetary policy.”<sup>5</sup> In our experiment we will compare welfare under economic transparency with welfare under the pure (no economic transparency) discretionary and commitment regimes. As is well known from Geraats (2002, 2014), a discretionary regime with economic transparency combines a lack of credibility with a lack of flexibility since any policy responses of monetary policy to supply shocks are perfectly foreseen and therefore cannot affect employment. The inflation bias in the discretionary regime with economic transparency is the same as in the discretionary regime without economic transparency, but the monetary policy response to supply shocks, is larger when there is economic transparency, causing a higher variation of inflation rates without stabilizing employment. The reason why the money supply responds so strongly to supply shocks is due to timing: the CB responds to private sector expectations that have already responded to the supply shock. Consequently, the total impact of shocks on inflation gets magnified under economic transparency. This regime combines time-inconsistent levels of inflation with time-inconsistent responses to shocks.

We next consider the commitment regime. In this environment the CB moves first and commits to set  $m$  in advance of the private sector’s formation of inflation expectations, but the CB may be able to condition this decision on realizations of the shock,  $w$ . The CB assumes that the private sector forms rational expectations,  $\pi^e = E(\pi|m) = m$ . Thus in this setting, the central bank’s minimization problem is:

$$\min_m E[b(m + v - \pi^*)^2 + (u_n - c(m + v - \pi^e) + w - u^*)^2|\sigma], \text{ s.t. } \pi^e = m.$$

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<sup>5</sup> Economic transparency concerns release of macroeconomic data and projections made by the central bank.

The solution, which we refer to as the one-shot commitment (C) equilibrium is given by  $m^C = \pi^*$ .

Under commitment, the central bank cannot create surprise inflation. Hence, it cannot stabilize the real economy and so its best policy is to target the desired inflation rate irrespective of the supply shock. Comparing this case to the Nash equilibrium under economic transparency, both problems of time inconsistency are solved by the CB's ability to commit: inflation is both stable and at the desired level. In comparison to the discretionary regime without economic transparency, however, we observe that while there is no inflationary bias, as  $\pi^* < \pi^{NE}$ , the inability to stabilize the real sector under commitment causes welfare losses that can be avoided under discretion.<sup>6</sup> This reflects the well-known trade-off between credibility and flexibility of monetary policy. This trade-off can be mitigated in the repeated (dynamic game) model where the private sector can condition its behavior on the central bank's past responses to supply shocks, so that reputational considerations come into play. We now turn our attention to that setting.

### 3.2 Dynamic model

Barro and Gordon (1983b) argue that time inconsistency can be overcome by reputation, if the central bank is sufficiently patient. In a repeated-game version of the model described in the previous section, there are multiple equilibria and central bank and private sector can coordinate on an equilibrium that is more efficient than the repeated one-period Nash equilibrium. If the central bank's long-run advantages from a reputation for low inflation are higher than the immediate rewards from surprise inflation, it can overcome the time inconsistency problem and achieve an efficient equilibrium. Our experiment implements such a dynamic version of the game.

In each period of this dynamic game, the central bank has the option to exploit low inflationary expectations by surprising the private sector with an unexpected high inflation which reduces unemployment and raises welfare in that period. However, unexpected high inflation can trigger a rise in

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<sup>6</sup> Whether the benefit from a flexible policy response to such shocks outweighs the costs arising from the inflationary bias of discretionary policy depends, of course, on the parameterization of the model.

future expectations about inflation which is to the central bank's disadvantage. Thus, the central bank has an incentive to keep inflation low, in order to maintain low inflationary expectations. Whether or not long-term reputational considerations for low inflation dominate short-term welfare gains from surprise inflation depends on parameters and on the effect of current inflation on future expectations. The highest incentive to keep inflation low arises if expectations are driven up forever. Here, we focus on conditions under which the efficient linear Ramsey rule can be sustained as an equilibrium of the infinitely repeated game.

In the repeated game, the central bank's objective is to

$$\min_{\{m_t\}} E_t \sum_{t=0}^{\infty} \delta^t [b(\pi_t - \pi^*)^2 + (u_t - u^*)^2 | w_t]$$

subject to the given processes for  $\pi_t$  and  $u_t$ . Depending on the information available to the private sector, e.g., whether they learn ex-post about the policy rule  $m(w)$ , and provided that the discount factor  $\delta$  is sufficiently large, the Folk theorem for infinitely repeated games implies that set of equilibrium payoffs ranges from the value in the one-period discretionary Nash equilibrium, where  $m_t = \pi^{NE} + \frac{c}{b+c^2} w_t$  and private sector expectations satisfy  $\pi_t^e = \pi^{NE}$  to the efficient linear "Ramsey" solution where the central bank sets  $m_t = \pi^* + \frac{c}{b+c^2} w_t$ , avoiding the inflation bias, because  $\pi_t^e = \pi^*$ , but at the same time having the flexibility to stabilize employment.<sup>7</sup> As this environment involves a multiplicity of equilibria with no clear means of choosing from among this set of equilibria, a laboratory experiment can be informative as to which equilibria agents are likely to coordinate on and under what conditions.

Before turning to the experimental design, we will briefly derive the conditions under which the Ramsey solution is an equilibrium of the repeated game. We assume throughout that the private sector will

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<sup>7</sup> The efficient linear solution can be derived by minimizing the central bank objective by a function  $m(w_t)$  s.t.  $E(\pi_t) = \pi^*$ . A formal derivation of the Ramsey solution is provided in Appendix A. The Ramsey rule can be sustained as equilibrium if  $\delta$  is sufficiently large. Suppose the private sector deviates to  $\pi_t^e = \pi^{NE}$  forever, if the central bank deviates from the optimal policy rule once. Then the central bank faces a loss forever. If  $\delta$  is large, the present value of this loss is higher than the gain from a one-time deviation. The critical value for  $\delta$  will be derived below.

learn inflation  $\pi_t$  and unemployment  $u_t$  at the end of each period. Knowing the Phillips curve, it can thereby deduce the supply shock  $w_t$  and condition its expectations on past realizations of these variables. Observability of past inflation gives the central bank an incentive to keep inflation low, observability of supply shocks allows for an equilibrium in which the central bank can efficiently respond to these shocks without compromising expectations. We need to distinguish, though, whether or not the private sector will get informed about the actual policy  $m_t$  and thereby the transmission shock  $v_t$ .

If policy is transparent such that the private sector can observe policy choices  $m_t$  (as assumed by Barro and Gordon (1983b)), expectations in period  $t+1$  can be conditioned on the actual relationship between  $m_t$  and  $w_t$ . The strongest incentive for the central bank to pursue the Ramsey rule is supported by a grim trigger strategy played by private sector agents in which their expectations are initially  $\pi_0^e = \pi^*$  in the first period and remain there, so long as the central bank follows the Ramsey rule. If, however, the central bank deviates from this policy in any period  $\tau$ , the private sector's expectations immediately jump towards the one-period Nash equilibrium  $\pi_t^e = \pi^{NE}$  for all  $t > \tau$ , and the best response for the central bank is to follow the Nash-equilibrium policy  $m^{NE}$  in all future periods. Thus, the central bank faces the trade-off between exploiting low expectations and raising employment for one period on the one hand and implementing the maximum equilibrium inflation bias for all future periods as the result. If the central bank deviates in say period 0, it should best respond to  $\pi_0^e = \pi^*$  and  $w_0$ , which yields  $m_0 = \pi^* + \frac{c}{b+c^2}(u_n - u^* + w_0)$  and gives rise to a welfare loss of

$$\begin{aligned}
& L_0^D(w_0) \\
&= E \left[ b \left( \frac{c}{b+c^2}(u_n - u^* + w_0) + v_0 \right)^2 + \left( u_n - c \left( \frac{c}{b+c^2}(u_n - u^* + w_0) + v_0 \right) + w_0 - u^* \right)^2 \middle| w_0 \right] \\
&= b \left( \frac{c}{b+c^2}(u_n - u^* + w_0) \right)^2 + b\sigma_v^2 + \left( \frac{b}{b+c^2}(u_n - u^* + w_0) \right)^2 + c^2\sigma_v^2 \text{ [skip this line in publication]} \\
&= \frac{b}{b+c^2}(u_n - u^* + w_0)^2 + (b+c^2)\sigma_v^2.
\end{aligned}$$

The expected welfare loss associated with a deviation from Ramsey is then given by  $L_0^D(w_0) + \sum_{t=1}^{\infty} \delta^t E(L^{NE})$ , where  $E(L^{NE})$  is the prior expected welfare loss in the one-period Nash-equilibrium:

$$\begin{aligned} E(L^{NE}) &= E \left[ b \left( \frac{c}{b} (u_n - u^*) + \frac{c}{b+c^2} w + v \right)^2 + \left( u_n - c \left( \frac{c}{b+c^2} w + v \right) + w - u^* \right)^2 \right] \\ &= \frac{b+c^2}{b} (u_n - u^*)^2 + \frac{c^2}{b+c^2} \sigma_w^2 + (b+c^2) \sigma_v^2. \end{aligned}$$

This must be compared with the expected welfare loss if the central bank follows the Ramsey rule. In the first period, this loss is given by

$$\begin{aligned} L^R(w_0) &= E \left[ b \left( \frac{c}{b+c^2} w_0 + v_0 \right)^2 + \left( u_n - c \left( \frac{c}{b+c^2} w_0 + v_0 \right) + w_0 - u^* \right)^2 \middle| w_0 \right] \\ &= b \left( \frac{c}{b+c^2} w_0 \right)^2 + b \sigma_v^2 + \left( u_n - u^* + \frac{b}{b+c^2} w_0 \right)^2 + c^2 \sigma_v^2 \quad [\text{skip this line in publication}] \\ &= (u_n - u^*)^2 + \frac{b}{b+c^2} (w_0^2 + 2w_0(u_n - u^*)) + (b+c^2) \sigma_v^2. \end{aligned}$$

The period-0 expectation of future losses under Ramsey is

$$\begin{aligned} E(L^R) &= E \left[ b \left( \frac{c}{b+c^2} w + v \right)^2 + \left( u_n - c \left( \frac{c}{b+c^2} w + v \right) + w - y^* \right)^2 \right] \\ &= (u_n - u^*)^2 + \frac{c^2}{b+c^2} \sigma_w^2 + (b+c^2) \sigma_v^2. \end{aligned}$$

Thus, the central bank has *no* incentive to deviate, if and only if  $L_0^D(w_0) + \sum_{t=1}^{\infty} \delta^t E(L^{NE}) \geq L_0^R(w_0) + \sum_{t=1}^{\infty} \delta^t E(L^R)$ , which is equivalent to

$$\begin{aligned} \frac{b}{b+c^2} (u_n - u^* + w_0)^2 - (u_n - u^*)^2 - \frac{b}{b+c^2} (w_0^2 + 2w_0(u_n - u^*)) &\geq \sum_{t=1}^{\infty} \delta^t \left[ -\frac{c^2}{b} (u_n - u^*)^2 \right] \\ \Leftrightarrow \frac{-c^2}{b+c^2} (u_n - u^*)^2 &\geq \frac{-\delta}{1-\delta} \cdot \frac{c^2}{b} (u_n - u^*)^2 \Leftrightarrow (1-\delta)b \leq \delta(b+c^2) \Leftrightarrow \delta \geq \frac{b}{2b+c^2}. \end{aligned} \quad (1)$$

This condition is necessary and sufficient for the Ramsey solution to be an equilibrium under transparent monetary policy.

If policy is not transparent, the private sector cannot perfectly infer whether an increase in inflation is due to the central bank's deviating from the Ramsey rule or to an unfortunate realization of the transmission shock,  $v_t$ . Here, the parameter restrictions that support the Ramsey equilibrium depend on the distribution of both shocks. In our experiment, we will use uniform distributions with bounded support. This allows us to derive a sufficient condition under which the Ramsey solution is an equilibrium.<sup>8</sup>

Suppose  $v$  has a uniform distribution in  $[-\mu, \mu]$  and consider the following strategy of forecasters: Expectations start at Ramsey and switch to Nash forever from period  $t + 1$  onwards, if  $\pi_t > \pi^* + \frac{c}{b+c^2} w_t + \mu$ . As long as the central bank plays Ramsey, the probability of expectations switching to Nash is zero. However, the central bank may raise the money supply just enough to exploit the large marginal gains for reducing unemployment from high levels at the risk of a moderate probability of being punished in the future. If  $\mu$  is large, the probability of detection is small, provided that  $m$  exceeds  $\pi^*$  just slightly. The CB can hide behind the shock, which may provide an incentive for deviations from Ramsey. For deriving a sufficient condition that prevents such incentives, first note that the marginal gain from increasing employment in the current period is a concave function of the money supply due to the quadratic loss function. The marginal expected future loss stemming from the probability of being detected, however, is linear due to the uniform distribution of transmission shocks.

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<sup>8</sup> Henckel et al. (2011) discuss this problem for a normally distributed shock and a welfare function that is linear in output. They assume that expectations switch to the one-period Nash equilibrium for one period if a certain test statistic indicates that the central bank has been cheating with some given probability. However, the test statistic is chosen arbitrarily and it is assumed that the central bank does not strategically game the test statistic. Under these conditions, the Ramsey solution cannot be sustained as equilibrium.

Define  $m^R = \pi^* + \frac{c}{b+c^2} w_t$ . If the money supply rises from  $m = m^R$  to higher levels  $m \in (m^R, m^R + 2\mu)$ , the probability of being detected is  $prob(\pi > m^R + \mu | m) = \frac{m - m^R}{2\mu}$ .<sup>9</sup> The associated expected welfare loss in the current period, say  $\tau = 0$ , is

$$\begin{aligned} E(L|w_0, m) &= E[b(m + v - \pi^*)^2 + (u_n - c(m + v - \pi^*) + w_0 - u^*)^2 | w_0] \\ &= b(m - \pi^*)^2 + b\sigma_v^2 + c^2(m - \pi^*)^2 - 2c(m - \pi^*)(u_n - u^* + w_0) + (u_n - u^* + w_0)^2 + c^2\sigma_v^2 \text{ [skip]} \\ &= (b + c^2)(m - \pi^*)^2 - 2c(m - \pi^*)(u_n - u^* + w_0) + (u_n - u^* + w_0)^2 + (b+c^2)\sigma_v^2. \end{aligned}$$

Thus, the marginal expected gain from increasing  $m$  is

$$-\frac{\partial E(L|w_0, m)}{\partial m} = 2c(u_n - u^* + w_0) - 2(b + c^2)(m - \pi^*).$$

The marginal expected loss is

$$\frac{1}{2\mu} \sum_{t=1}^{\infty} \delta^t (E(L^{NE} - L^R)) = \frac{\delta}{1-\delta} \cdot \frac{c^2}{2\mu b} (u_n - u^*)^2.$$

A marginal deviation from Ramsey does *not* pay off, if and only if

$$2c(u_n - u^* - w_0) \leq \frac{\delta}{1-\delta} \cdot \frac{c^2}{2\mu b} (u_n - u^*)^2 \Leftrightarrow 4\mu b(u_n - u^* - w_0) \leq \frac{\delta}{1-\delta} \cdot c(u_n - u^*)^2.$$

Clearly, the incentive for inflating the economy rises with larger supply shocks. Since we assume a bounded support, a sufficient condition preventing deviations from Ramsey is

$$\begin{aligned} 4\mu b(u_n - u^* + w_{max}) &\leq \frac{\delta}{1-\delta} \cdot c(u_n - u^*)^2 \\ \Leftrightarrow (1 - \delta)4\mu b(u_n - u^* + w_{max}) &\leq \delta c(u_n - u^*)^2 \text{ [skip this line in publication]} \\ \Leftrightarrow 4\mu b(u_n - u^* + w_{max}) &\leq \delta [c(u_n - u^*)^2 + 4\mu b(u_n - u^* + w_{max})] \text{ [skip this line in publication]} \end{aligned}$$

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<sup>9</sup> If money supply is larger, the deviation from Ramsey will be detected for sure. Condition (1) ensures that this is not in the interest of the central bank.



$$\Leftrightarrow \delta \geq \frac{4\mu b(u_n - u^* + w_{max})}{c(u_n - u^*)^2 + 4\mu b(u_n - u^* + w_{max})}, \quad (2)$$

where  $w_{max}$  is the largest possible realization of the adverse supply shock. In the experiment, we will make sure that Conditions (1) and (2) hold.

#### 4. Experimental Design and Hypotheses

Our experimental design consists of six different treatments that vary in the timing of moves and in the information available to participants. However, across all treatments, a number of factors were held constant and we begin with this basic structure.

##### 4.1 Baseline Design

Each session of a given treatment involved 20 subjects with no prior experience with this experiment. The experiment was conducted over networked computers and was programmed using the z-Tree software (Fischbacher 2007). At the start of each session, subjects were randomly divided up into two matching groups of size 10. Subjects in different matching groups never interacted with each other and thus each matching group (2 per session) constitutes an independent observation. A session for each matching group consists of a number of repeated games known as “sequences” with each sequence consisting of an unknown number of rounds.

At the start of each new sequence, subjects in each matching group were randomly divided up into two groups of size 5 and the composition of the group remained constant for all rounds of the sequence. Prior to play of the first round of each sequence, one member of each group was randomly selected to play the role of the central banker, known as the “type A” player, while the other four members of each group were assigned to play the role of the private sector, known as “type B” players.<sup>10</sup> Subjects remained in the *same*

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<sup>10</sup> Our choice of having a single central banker and a larger “private sector” of four players follows the setup of Arifovic and Sargent (2003) and reflects that fact that the private sector is considerably larger than the government sector. An alternative arrangement would have been to have the central bank consist of a *committee* of decision-makers (more than 1 player) as in Blinder and Morgan (2005). While we think central bank committees would be an interesting extension, we chose to have a single central banker in the interest of saving time and obtaining more observations.

role in all rounds of a given supergame. At the start of each new sequence, groups were randomly formed anew and the type A player was again randomly chosen from among the membership of the new group, so that there is turnover of central bankers in our environment.

To avoid triggering any pre-conceived notions of the proper role or choices to be made by each player type, we used neutral language and a neutral framing of the model as detailed below. Specifically, we avoided any references to central banks, inflation, unemployment etc. as such contextualization may lead to a loss of control over the incentives of the experiment<sup>11</sup>. We wanted the incentive structure of the model to be the main determinant of subjects' decisions as it is in the theory.

We told subjects to imagine that the two variables,  $u_t$  and  $\pi_t$ , stand for two “containers” holding varying amounts of water<sup>12</sup>. Subjects were instructed that at the start of each round  $t = 1, 2, \dots$ , container 1 (unemployment) held  $W_t$  “gallons” (“liters”) of water where  $W_t$  was publicly known to be an i.i.d. random draw each period from a uniform distribution over the interval  $[120, 160]$ . The expected value,  $E[W_t] = 140$ , corresponds to the NAIRU,  $u_n$ , in the model while the supply shock  $w_t = W_t - E[W_t]$ . Thus, in our parameterization one can think of the adverse supply shock,  $w_t$ , as an i.i.d. random draw from a uniform distribution with support  $[-20, 20]$  and thus having mean 0 and standard deviation  $20/\sqrt{3} = 11.55$ . The initial amount of water in Container 1 (unemployment) thus consists of both the NAIRU and the adverse supply shock, i.e.,  $W_t = u_n + w_t$ . The timing of when or whether players learned the value of  $W_t$  is an important element of our treatments. Subjects were further instructed that Container 2 (inflation) was initially empty.

In our baseline, discretionary policy treatment, the timing of moves was as follows. The four type B players in each economy moved first each submitting a forecast,  $\pi_{t,t}^e$ , as to how many gallons (liters) of

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<sup>11</sup> For instance, subjects might be averse to raising “unemployment” even though according to the incentive structure of the game, it may be payoff maximizing to do so.

<sup>12</sup> The idea of framing a monetary policy game in terms of targeting amounts of water or chips in a container has been used first by Engle-Warnick and Turdaliev (2010). Phillips (1950) actually describes a hydraulic machine that was built to demonstrate the effects of fiscal and monetary policy in an IS-LM-framework.

water would be in Container 2 at the end of round  $t$ . They did so without knowing the realized value of  $W_t$ , though they *did* know that  $W_t$  was an i.i.d. random draw from a uniform distribution on the interval [120, 160] and they were told that  $E[W_t] = 140$ . They were also informed about the player A's objective function (as described below), so they knew the Player A's (central bank's) target values for inflation,  $\pi^*$ , and unemployment,  $y^*$ . After all four Player Bs had made their forecasts, the computer program calculated the mean forecast  $\pi_t^e = \frac{1}{4} \sum_{i=1}^4 \pi_{i,t}^e$  for the economy/group and revealed this value to the group's Player A – this forecast corresponds to  $\pi_t^e$  in the model. Subjects were instructed that this average forecast value would be added to the amount of water that was already in Container 1, so that the amount of water in Container 1 now increased to  $W_t + \pi_t^e$ . Then, the player A alone in each group learned the value of both  $W_t$  and  $\pi_t^e$  and the sum  $W_t + \pi_t^e$ , representing the new total amount of water in Container 1. Player A was then instructed to “move” some amount  $m \in [0,80]$  of water from Container 1 to Container 2. This choice corresponds to the policy choice of  $m_t$  for period  $t$ . In the baseline discretionary treatment, Player Bs do not observe Player A's choice for  $m_t$  but it is public knowledge that  $m \in [0,80]$ . In addition, it was public knowledge to both player types that there was a random, uncontrolled flow of water,  $v_t$ , from Container 1 to Container 2, corresponding to the policy transmission shock of the theory. The value of  $v_t$  was publicly known to be an independent random draw each period from a uniform distribution having support [0, 40] and all subjects were instructed that  $E[v_t] = 20$ . Note that differently from the theory, the transmission shock is not mean zero; this choice was made because the policy action space was  $m \in [0,80]$ , and we did not want to have inflation  $\pi_t = m + v_t$  be negative. Player As do not observe the value of  $v_t$  until after they have chosen  $m_t$ .

At the end of each period  $t$ , the final amount of water in Container 1 is thus given by  $W_t + \pi_t^e - m_t - v_t$ , which correlates to the Phillips curve relationship, in which surprise inflation reduces unemployment. Setting the parameter of the Phillips curve  $c = -1$ , as we do in all treatments of our experiment, we have that the final amount of water in Container 1 corresponds to  $u_t = u_n + w_t + \pi_t^e - \pi_t$  while the final

amount of water in Container 2 corresponds to  $\pi_t = m_t + v_t$ . This simple additive structure made it easy for subjects to understand the rules of the game.

The final amounts of water in Containers 1 and 2 were revealed to all subjects in each economy of size 5 at the end of each period as these amounts determined the subjects' payoffs for the round. Specifically, each player type was incentivized to make choices consistent with the objective functions posited by the theory. Type A players were instructed that their point earnings were given by the formula:

$$\text{Player A Points} = 6000 - 2 (\text{Final Container 1 amount} - 120)^2 - (\text{Final Container 2 amount} - 40)^2.$$

Thus, Player A's (central bankers) had as their policy objectives:  $u^* = 120$  and  $\pi^* = 40$  and the parameter  $b$  was set equal to  $\frac{1}{2}$ . As noted above, the payoff function and the parameter choices for Player As were public knowledge to all participants as revealed in the written instructions. Type B players were instructed that their point earnings were given by the formula:

$$\text{Player B Points} = 4000 - (\pi_{i,t}^e - \text{Final Container 2 amount})^2.$$

Thus, Player B's had the simpler task of just forecasting the value for  $\pi_t$ , the amount of water in Container 2 correctly.<sup>13</sup> For this reason, the maximum number of points that Player Bs could earn each round was 4,000, while Player A's, who had the more difficult decision, could earn a maximum of 6,000 points per round. These equations determining players' points were presented to both player types and for ease of understanding, subjects were given payoff tables showing how their choices would convert into points each

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<sup>13</sup> The realized levels of inflation and unemployment do not enter into the payoff functions of forecasters, only the payoff functions of the central bankers. We are assuming that inflation forecast accuracy is all that matters to forecasters; given accurate inflation forecasts these agents would be able to infer the level of unemployment (output) from knowledge of the model and solve any profit or utility maximizing problems that they faced. Restricting private sector agents to forming inflation forecasts alone (a "learning to forecast" design) also limits such agents' incentives to affect aggregate variables such as unemployment and inflation which they might otherwise have incentives to influence given the small group sizes of the economies that we study. Thus our restriction that private sector agents provide forecasts only is also consistent with standard assumptions of perfectly competitive behaviour by private sector agents.

round. The experimental instructions including these payoff tables and other details about what subjects were told are provided in Appendix B. The parameterization of the model is justified in section 4.3.

At the end of each round, all subjects are informed of the final amounts of water in the two containers corresponding to the realizations of  $u_t$  and  $\pi_t$  and their point earnings for the round as determined by the expressions given above. In addition, type B players learn the realization of  $W_t$  and thereby the realization of the supply shock  $w_t = W_t - E(W)$  at the end of the period. Whether type B players learn the central banker's choice for  $m_t$  depends on the treatment as detailed below.

Subjects were instructed that at the end of each round the computer would draw a number randomly from the set  $\{1,2,3,4,5,6\}$ . They were further instructed that if a six was drawn, the sequence ended but otherwise the sequence would continue with another round. This constant random continuation probability implements both discounting with factor  $\delta = \frac{5}{6}$  and the stationarity associated with an infinite horizon. Subjects were instructed that, depending on the time remaining in the session, a new sequence of indefinite length might begin.

Subjects were informed that at the end of the session (which could last up to three hours), two sequences would be chosen from among all sequences played and subjects' point earnings from the chosen sequences would be converted into cash at a known and fixed rate. In addition, at the start of *each* sequence subjects were endowed with 5,000 points to avoid negative payoffs; since two sequences were chosen for payment at the end, the endowment of  $2 \times 5,000$  points served as subjects' show-up payment (equivalent to €5 in Germany, \$5 in U.S.).

## 4.2 Treatments

Our experiment consists of six different treatments that are intended to explore the role (if any) played by reputation, cheap talk and transparency (both policy and economic) on welfare in the repeated discretionary environment relative to an environment where central banks can commit to monetary policy. The six treatments are:

1. **Discretionary policy:** The timing and moves for this baseline treatment are as described in Section 4.1. The private sector, type Bs, move first and are not informed of the realization of the supply shock  $w_t$  when forming their expectations,  $\pi_{i,t}^e$ . The policy maker observes  $w_t$  and  $\pi_t^e$  and then chooses  $m_t$ . Type Bs never learn the value of  $m_t$  or  $v_t$ , but they do learn the final amounts of water in each container,  $u_t$  and  $\pi_t$  and are informed of the values for  $w_t$  and  $\pi_t^e$  at the end of the period.

2. **Commitment:** In this treatment, the central banker, Type A moves first, observing the realization of the supply shock,  $w_t$  and then choosing  $m_t$  prior to the formation of inflationary expectations by the private sector. Thus the commitment environment we study provides the central banker with the ability to respond to supply shocks but also to commit to an inflation policy for the period.

3. **Cheap talk (CT):** In this treatment, Type A players again move first, observing the value of the supply shock  $w_t$  and then choose a message of the form: “The amount of water I intend to move from Container 1 to Container 2 is \_\_\_.” In the blank space they enter the value of  $m \in [0,80]$  that they want to signal to forecasters in that round. This message is sent to all Player Bs in their group. Then the Player Bs form their forecasts of inflation for the period,  $\pi_{i,t}^e$ . Recall that Player Bs understand that the final amount of water in Container 1,  $\pi_t = m_t + v_t$ , so the announcement concerning the intended choice for  $m_t$  can play a role in coordinating private sector inflationary expectations. To ensure that the message is understood to be cheap talk, subjects are further instructed that “it is up to Player A whether he or she moves as much water as previously announced. Player A can move the announced amount or more or less water.”

4. **Policy transparency (PT):** This treatment has the same timing as the baseline discretionary treatment. The only difference is that the private sector Type B players learn the realizations of both  $m_t$  and  $v_t$  at the end of each round, immediately after the central bank has made these choices thus making it transparent as to whether inflation was high (low) due to the transmission shock or due to the policymaker’s choice. This timing is consistent with Geraats’s (2002, p. F540) definition of policy transparency as the “prompt

announcement and explanation of policy decisions.<sup>14</sup> A transparent policy environment such as in this and the next treatment (cheap talk plus policy transparency) makes it easier to sustain the Ramsey solution as equilibrium of the repeated game.

**5. Cheap talk and policy transparency (CT+PT):** This treatment combines the cheap talk phase of the cheap talk treatment with the information revealed about monetary policy ( $m_t$  and  $v_t$ ) at the end of each round as in the policy transparency treatment. This treatment thus allows the private sector to evaluate the truthfulness of the central bank's cheap talk announcements providing a potentially more credible means by which the central bank can attempt to manage private sector expectations as compared with cheap talk or policy transparency by themselves.

**6. Economic transparency (ET):** In this treatment, the private sector (Player Bs) learn the value of the supply shock  $w_t$  at the same time that the central banker (Player A) learns it, and prior to forming expectations of inflation for the period. The timing and information is otherwise identical to that of the discretionary treatment.

### 4.3 Calibration and Interpretation

Parameter choices had to satisfy different requirements: subjects must be able to comprehend the relation between different variables, the different equilibria should be sufficiently differentiated, allowing us to detect treatment effects and potentially reject hypotheses, the parameters should allow for an interpretation as a monetary policy game, the continuation probability should allow for several sequences per session and also satisfy the conditions for the Ramsey solution to be an equilibrium. While the levels of the

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<sup>14</sup> Policy transparency can also include “an indication of likely future policy actions” Geraats (2002, p. F540), which is related to forward guidance, but we abstract from this possibility in our policy transparency treatment. Among other forms of transparency, Geraats refers to political transparency as “openness about policy objectives and institutional arrangements” – the rules of the game and payoff function of the central bank. Since we always provide such information to our subjects, political transparency is present in all of our treatments. Similarly, we also have “operational transparency” in all of our treatments in the sense that we reveal the distribution of transmission shocks. We do not consider “procedural transparency” which includes revelation of the central bank's strategy, as this would require that subjects submit strategies for policy decisions, and the strategy space is too large to elicit such strategies.

unemployment and inflation target  $u^*$  and  $\pi^*$  are mere normalizations, the other parameters affect the interpretation.

We suggest that a period in the experiment corresponds to 2 years, our guess regarding the length of time it takes for monetary policy to have an impact on inflation and unemployment. Thus our continuation probability choice of  $\delta = 5/6$  means that the expected duration of a supergame (or a CB policy regime) is 12 years and implies an annual discount rate of about 8 percent. We assume that the difference between natural and efficient unemployment is 2 percent. As we set  $u_n = 140$  and  $u^* = 120$ , the difference between efficient and natural unemployment is 20, so we may think of units of  $u$  as equaling 0.1 percent unemployment. We suppose that a 1 percent increase in inflation leads to a .5 percent reduction in unemployment. Setting  $c = 1$ , thus, implies that units of  $\pi$  must correspond to .2 percent inflation. Since the standard deviation of supply shocks  $w$  is 11.55 and a unit of  $u$  is .1 percent unemployment, the standard deviation of supply shocks in the experiment is about 1.15 percent unemployment. The transmission shock,  $v$ , also has a standard deviation of 11.55 and since a unit of  $\pi$  is .2 percent inflation; the standard deviation of policy transmission shocks in the experiment is 2.3 percent inflation. The parameter choices with  $b = .5$  also imply that the inflation bias in the one-period Nash equilibrium is  $\frac{c}{b}(u_n - u^*) = 40$  and, since units of  $\pi$  correspond to .2 percent inflation, corresponds to 8 percent inflation. Finally, we note that the optimal coefficient attached to supply shocks in the one-period Nash equilibrium and in the Ramsey solution is  $\frac{c}{b+c^2} = \frac{2}{3}$ . Suppose that the economy is hit by a shock that would increase unemployment by 1% without further policy measures ( $w = 10$ ). In our economy, the optimal response would be an increase of  $\pi$  by 6.67 corresponding to 1.33% inflation. This policy reduces the increase in unemployment to .67%.

Note that the condition for existence of a Ramsey equilibrium in the repeated game under policy transparency requires  $\delta \geq \frac{b}{2b+c^2} = 0.25$ . With  $\mu = 20$  and  $w_{max} = 20$ , the sufficient condition for the Ramsey solution to be an equilibrium in the regimes without policy transparency is



$$\delta \geq \frac{4\mu b(u_n - u^* + w_{max})}{c(u - u^*)^2 + 4\mu b(u_n - u^* + w_{max})} = \frac{40 \cdot 40}{(20)^2 + 40 \cdot 40} = 0.8.$$

Naturally, it is more challenging than the condition under policy transparency. Our discount factor of  $\delta = 5/6$  satisfies both requirements.

#### 4.4 Experimental Hypotheses

Given our parameterization of the model, theory predictions are summarized in Table 1, which reports point predictions if all equilibria give the same predictions or upper and lower bounds for the range of equilibria. The commitment solution is for the CB to set  $m_t = m = 20$  for all  $t$  since  $E[v_t] = 20$ , and therefore  $E[\pi_t] = m + E[v_t] = 40 = \pi^*$ . As laid out in Section 3.1, the CB should not respond to supply shocks, because any such response would be reflected in forecasts and, thus, not affect employment. It follows that inflation varies only with the transmission shock,  $\text{Std}[\pi] = \text{Std}[v] = 11.55$ , while the variance of unemployment is the sum of the variances of the two shocks, or  $\text{Std}[u] = \sqrt{\text{Var}[v] + \text{Var}[w]} = 16.33$ . Expectations should be rational and equal to  $\pi^*$ , so that the standard deviation of  $\pi_t^e - \pi_t$  should simply reflect the standard deviation of the policy transmission shock,  $\text{Std}[v] = 11.55$ . Expected CB welfare is given by

$$6000 - 2E((140 - 120 - w - v)^2) - E(v^2) = 5200 - 2\text{Var}(w) - 3\text{Var}(v) = 4533.3.$$

In the case of discretion, we have multiple equilibria ranging from the one-period Nash with an inflation bias of 40 to the Ramsey solution without inflation bias. In all equilibria, the CB responds to supply shocks and stabilizes employment with a coefficient of  $\partial m / \partial w = 2/3$ . The same coefficient applies to the central bank's response to inflation expectations, as given by the response function (1). Note however that in a Ramsey equilibrium forecasts are constant and, thus, there should be no detectable variation to which the central bank responds. As subjects are most likely not exactly in equilibrium, the best response of the central bank with respect to "near Ramsey" expectations might still be zero. In the Result section, we will analyze whether subjects respond in an optimal way to the actual decision of other players. Assuming rational

expectations, the actual choices of  $m$  should range from  $\pi^* - E(v) + \frac{2}{3}w_{min} = 6.67$  under Ramsey to  $\pi^* + 40 + E(v) + \frac{2}{3}w_{max} = 73.33$ . Our subject central bankers can choose values of  $m \in [0,80]$ , which contains all of these vales in the interior, allowing us to test the point predictions associated with the most extreme equilibria. The inflation bias is given by the difference between chosen money supply and the Ramsey solution. On average it amounts  $\bar{m} + E(v) - \pi^* = \bar{m} - 20$ , where  $\bar{m}$  is the average money supply.

**Table 1: Equilibrium Predictions**

Treat. Predict	Commitment	Discretion	Cheap Talk	Policy Transparency	CT + PT	Economic Transparency
Inflation bias	0	[0,40]	[0,40]	[0,40]	[0,40]	[0,40]
Response of $m_t$ to supply shock, $w_t$ .	0	2/3	2/3	2/3	2/3	2/3 2 *
Response of $m_t$ to exp inflation, $\pi_t^e$ .	n.a.	2/3	2/3	2/3	2/3	2/3
Response of $\pi_t^e$ to supply shock, $w_t$	0	n.a.	0	n.a.	0	2
St.Dev. of $\pi_t$	11.55	13.88	13.88	13.88	13.88	25.82
St. Dev. of $u_t$	16.33	12.17	12.17	12.17	12.17	16.33
St. Dev. of ( $\pi_t^e - \pi_t$ )	11.55	13.88	13.88	13.88	13.88	11.55
CB Welfare	4533	[3111, 4711]	[3111, 4711]	[3111, 4711]	[3111, 4711]	[2400, 4000]
Forecasters' payoffs	3867	3807	3807	3807	3807	3867

Note: \* The response of  $m$  to the supply shock in ET should be 2/3 if the response to private expectations is controlled for. Since expectations respond to the supply shock as well, the total response of  $m$  to  $u$  should be 2.

The stabilization of employment raises the standard deviation of inflation to  $\text{Std}[\pi] = \sqrt{\text{Var}[v] + \frac{4}{9}\text{Var}[w]} = 13.88$ , while it reduces the standard deviation of unemployment to  $\text{Std}[u] = \sqrt{\text{Var}[v] + \frac{1}{9}\text{Var}[w]} = 12.17$ . Since inflation expectations are constant in any equilibrium, the standard deviation of  $\pi_t^e - \pi_t$  should equal the standard deviation of inflation.

In the Ramsey equilibrium, expected CB welfare is:

$$6000 - 2E\left(\left(140 - 120 - \frac{1}{3}w - v\right)^2\right) - E\left(\left(v + \frac{2}{3}w\right)^2\right) = 5200 - \frac{6}{9}\text{Var}(w) - 3\text{Var}(v) = 4711.1.$$

In the Nash equilibrium, however, expected welfare is lower, because of the inflation bias and is given by

$$6000 - 2E\left(\left(140 - 120 - \frac{1}{3}w - v\right)^2\right) - E\left(\left(40 + v + \frac{2}{3}w\right)^2\right) = 3600 - \frac{6}{9}\text{Var}(w) - 3\text{Var}(v) = 3111.1.$$

Notice that the discretionary regime admits a range of possible welfare values for the CB that includes the commitment welfare value in its interior.

Policy transparency, cheap talk, and policy transparency plus cheap talk have no impact on the set of equilibria. While cheap talk announcements should be ignored in equilibrium, they might transmit information about the supply shock to the private sector, which justifies testing the equilibrium prediction of expectations being unresponsive to supply shocks and announcements.

Under economic transparency, on the other hand, the private sector learns the supply shock prior to forming expectations. As laid out in Section 3.1, this raises the equilibrium coefficient by which money supply, inflation, and inflation expectations respond to supply shocks to  $c/b = 2$  without stabilizing employment, which results in  $\text{Std}[\pi] = \sqrt{\text{Var}[v] + 4\text{Var}[w]} = 25.82$ , while  $\text{Std}[u] = 16.33$  as in the commitment regime. Because the private sector can predict monetary policy responses to supply shocks, the standard deviation of  $\pi_t^e - \pi_t$  should simply reflect the policy transmission shock,  $\text{Std}[v] = 11.55$ . As in the baseline discretionary treatment, there is a set of equilibria, ranging from the one period Nash to a constrained efficient solution, in which there is no inflation bias, but no stabilization of employment either. Welfare in the one-period Nash is given by

$6000 - 2E\left(\left(140 - 120 - w - v\right)^2\right) - E\left(\left(40 + v + 2w\right)^2\right) = 3600 - 6\text{Var}(w) - 3\text{Var}(v) = 2400$ . In the most efficient equilibrium, welfare is

$$6000 - 2E((140 - 120 - w - v)^2) - E((v + 2w)^2) = 5200 - 6\text{Var}(w) - 3\text{Var}(v) = 4000.$$

Beside the point predictions from equilibria, we have some more fundamental hypotheses that can be divided up between those pertaining to CB behavior, those pertaining to the behavior of the private sector and aggregate outcomes involving both sets of actors.

#### *Central Bank Hypotheses*

**Hypothesis 1.** *Repetition in the discretionary regime serves as a substitute for commitment regarding monetary policy.*

By this we simply mean that in the repeated game the A-player behaves as if s/he were operating under a commitment regime and (a) produces a similar average money supply. The counter-hypothesis is that a higher money supply arises from the inflation bias associated with the less efficient equilibria under discretion. (b) The second part of this hypothesis states that monetary responses to supply shocks are the same. Here, the counter-hypothesis comes from the positive coefficients in the equilibria of discretionary regimes.

**Hypothesis 2.** *The discretionary regimes with and without cheap talk, policy transparency, or economic transparency produce the same central bank behavior.*

More precisely, we test, (a) whether these treatments lead to the same average money supply and (b) to the same central bank responses to expected inflation and supply shocks.

#### *Private sector hypotheses*

**Hypothesis 3:** *Average private sector forecasts of inflation are unbiased and the distribution of forecast errors reflects the unpredictable fluctuations of inflation only.*

This hypothesis follows from the assumption of rational expectations. We will test whether biases are null and, if not, whether they differ across treatments.

**Hypothesis 4:** *The distribution of individual forecasts around the average is the same across treatments.*

Theory predicts that B-players make the most precise forecasts and earn the highest payoffs in the commitment treatment and under economic transparency, and lower (but equal) payoffs in the other discretionary treatments. Besides a treatment-specific bias, individual forecast errors reflect how much information about economic shocks and monetary policies the B-players have when they make their forecasts. We will test whether the standard deviation of average forecast errors is the same across treatments and how dispersed individual expectations are. While in equilibrium all agents hold the same expectations, in the experiment expectations will differ across subjects. These differences may be related to the treatment, even if the average forecast errors are the same across treatments. Related to this, the payoffs for type-B players might differ across treatments for three reasons: (i) there may be a systematic bias (cf. Hypothesis 3), (ii) average forecast errors may be more volatile in some treatments than in others (Std. of  $\pi_t^e - \pi_t$ ) and (iii) individual forecasts may be more or less dispersed (Std. of  $\pi_t^i - \pi_t^e$ ).

**Hypothesis 5:** *Except for the economic transparency regime, inflation forecasts do not respond to supply shocks.*

In the baseline discretionary treatment and for policy transparency, B-players do not receive any information that might eventually depend on supply shocks. In treatments with cheap-talk, the announcements should be ignored and under commitment, monetary policy should not respond to supply shocks. The counter-hypothesis (that forecasts are affected by supply shocks under commitment or cheap talk) arises from possible information transmission in these treatments, if either cheap-talk announcements or money supply under commitment respond to these shocks.

Finally, we have some hypotheses regarding *aggregate outcomes*:

**Hypothesis 6:** *Under commitment and economic transparency, output volatility is larger than in the other discretionary regimes.*

Here, we test whether output volatility is the same between ET and commitment, whether it is the same across the other treatments, and whether there are differences between these two groups of treatments.

**Hypothesis 7:** *Compared with discretionary treatments, the standard deviation of inflation should be higher under economic transparency and lower under commitment.*

**Hypothesis 8:** *Repetition in the discretionary regime serves as a substitute for commitment regarding (central bank) welfare.*

While the inflation bias in discretionary regimes may be higher than under commitment, the flexibility with which central banks can respond to supply shocks under discretion, may reduce employment fluctuations. Thus, there are two opposing effects for the final level of central bank welfare. This can be seen in Table 1, where equilibrium welfare under commitment is strictly in between the lowest and highest welfare levels associated with equilibria in discretionary treatments.

**Hypothesis 9:** *Under economic transparency, central bank welfare is lower than under commitment or in the baseline discretionary treatment.*

For economic transparency the welfare levels in all equilibria are lower than under commitment. The only welfare relevant difference between economic transparency and the baseline discretionary treatment is that economic transparency does not allow for stabilizing output (in theory). This justifies our last hypothesis.

We generally use non-parametric tests based on average observations from a matching group to compare levels. We apply this conservative treatment of data, because behavior of different subjects from the same matching group need not be independent. For point predictions arising from theory, we use the two-sided Wilcoxon matched pairs test, for comparing different treatments, we use the two-sided Mann-Whitney U-test. More precise coefficient predictions are tested on the basis of confidence intervals from fixed effects regressions, where the unit of observation is matching group, sequence (supergame) number and subject ID.

#### 4.5 Subjects, Sessions and Earnings

Each experimental session consisted of 20 inexperienced subjects who were further divided up into two “matching groups” of size 10; the subjects in each matching group never interacted with one another and thus each matching group constitutes an independent observation. We have 8 observations for each of our six treatments. One half of the sessions/observations were conducted at the Berlin University of Technology and the other half at the University of Pittsburgh<sup>15</sup>. As each observation involves 10 subjects, we thus report data from a total of  $8 \times 10 \times 6 = 480$  subjects. We did not find substantial differences in behavior between our two subject populations (Berlin and Pittsburgh) and so in the analysis that follows we have pooled the data from all matching groups of a given treatment.

At the start of each treatment, subjects were given written instructions that were also read aloud. Appendix B provides sample instructions from the baseline discretionary treatment.<sup>16</sup> Subjects then had to answer several quiz questions designed to check their comprehension of the written instructions. Subjects’ answers were individually checked for correctness; the experimenter explained to subjects any errors they made and what the correct answers should be. Then subjects played several indefinite-length sequences or “supergames” – they did not know how many would be played – and they were paid in cash at the end of the session. Each session lasted 2-3 hours (subjects were always invited for 3 hours) and involved 4-10 supergames. No session had to be continued, that is, all sessions finished within the 3 hour time frame for which subjects had been recruited. Subjects were paid their earnings from 2 supergames; one of these supergames was the one in which the subject had earned the highest payoff and one was chosen randomly from among the other supergames<sup>17</sup>. On average, each session involved 5.96 supergames with 34.1 rounds in total. Individual payoffs ranged from USD \$13.30 to \$56.46 with an average of about \$37.5.

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<sup>15</sup> Subjects were mainly Bachelor- and Master students of engineering, economics, and other majors at TU Berlin and undergraduates in various fields at the University of Pittsburgh

<sup>16</sup> Instructions for all 6 treatments are available at: <http://www.socsci.uci.edu/~duffy/CBExperiment/>

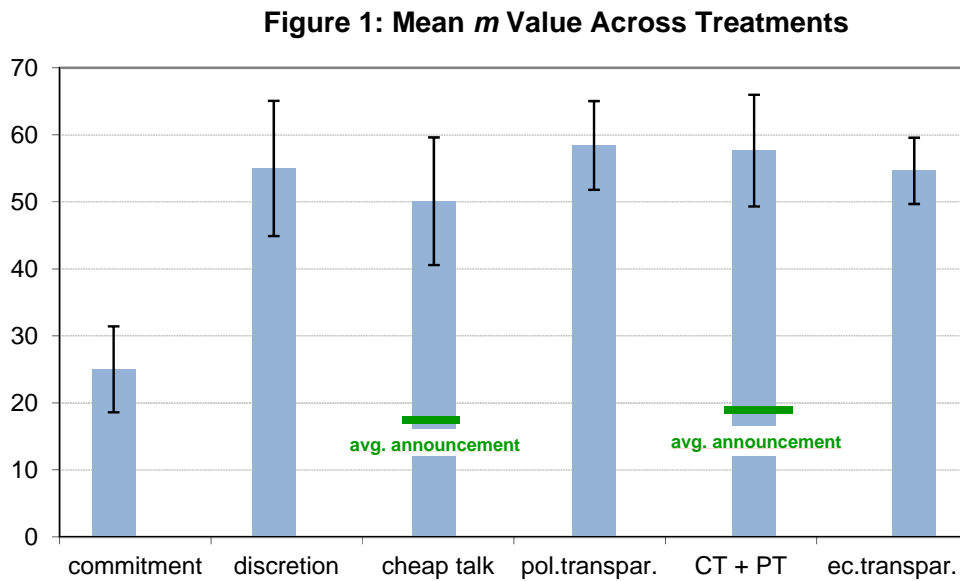
<sup>17</sup> The reason for selecting the sequence with the highest payoff was twofold: Typically, subjects in the role of central banker (Type A) earned more (per round) than subjects in role B. In addition, longer sequences typically lead to higher profits. Thus, Player As had high incentives to build up a reputation that pays off in long sequences.

## 5. Experimental Results

We report our experimental results as a number of different findings which address Hypotheses 1-9 as set forth in Section 4.4.

### 5.1 Money supply

Evidence in support of Finding 1 is presented in Figure 1 which shows the mean choice of  $m$  over all supergames of all sessions of each of our six treatments. Also included is a one-standard error bar and the mean announced value of  $m$  in the two treatments involving pre-game communication. The Figure shows clearly that the mean choice of  $m$  in the commitment treatment is indistinguishable from the Ramsey solution  $m=20$ , whereas the mean value of  $m$  in the other 5 treatments is significantly greater than 20.



**Finding 1:** *Inconsistent with Hypothesis 1a, reputation does not serve as a substitute for commitment in any of the five discretionary regimes.*

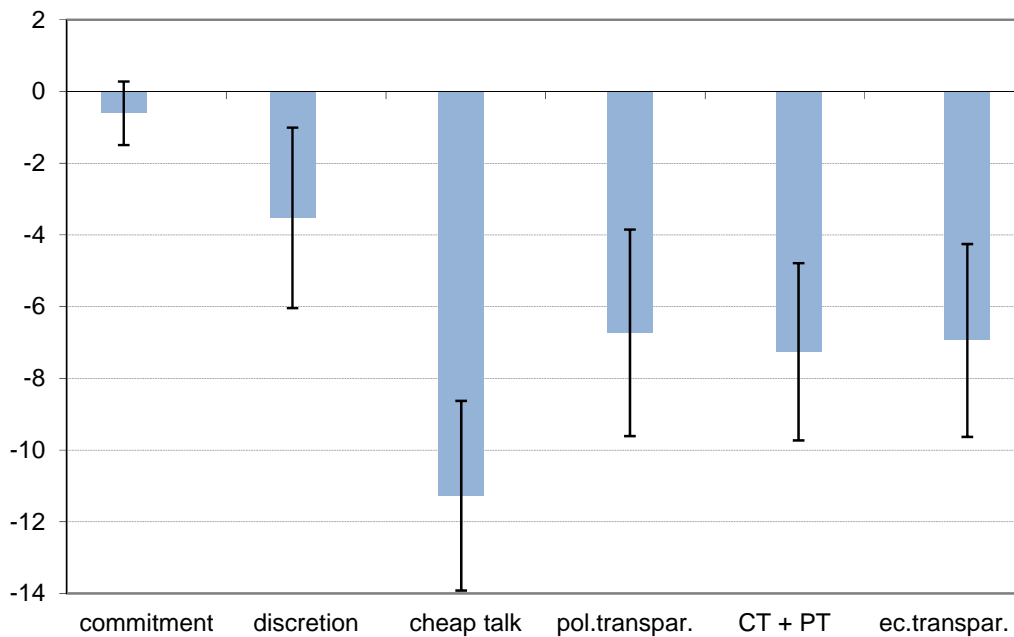
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Experimenting was ex ante costly for the Players A, because any new sequence could turn out to be long and the one providing the highest payoffs.



Two-sided Mann-Whitney U-tests show that the money supply under commitment is smaller than in any of the other treatments ( $p < 1\%$ ), while there are no significant differences between these other treatments ( $p > 5\%$ ). A two-sided Wilcoxon matched pairs test cannot reject that  $m=20$  under commitment ( $p=15\%$ ), but rejects this efficient value for all other treatments ( $p < 1\%$ ). The hypothesis that average money supply is equal to the point prediction of the one-period Nash equilibrium ( $m=60$ ) can be rejected for cheap talk ( $p=3.5\%$ ) and economic transparency ( $p=1.6\%$ ) treatments, but not for the other three discretionary treatments ( $p > 10\%$ ). These results suggest that the one-shot Nash equilibrium may be highly relevant in a repeated game, even if all of the theoretical conditions necessary for the Ramsey solution being an equilibrium hold. Furthermore, neither cheap talk, nor policy transparency, nor economic transparency are effective in reducing the inflation bias, which is consistent with Hypothesis 2a.

**Figure 2: Average forecast -  $m = 20$**

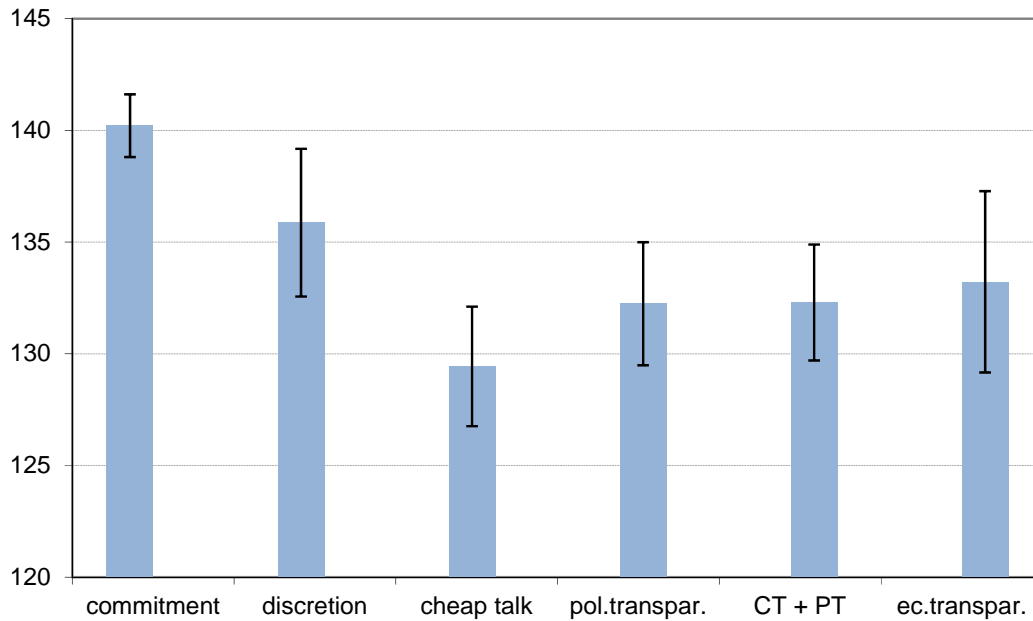


**Finding 2:** *Inconsistent with Hypothesis 3, private sector expectations are biased in the five discretionary treatments, though not in the commitment treatment. In the discretionary treatments, private sector agents systematically under-predict inflation.*

Evidence in support of Finding 2 is presented in Figure 2. Since inflation is equal to the money supply plus a transmission shock having an average value of 20, unbiased forecasts should equal  $m+20$ . While this hypothesis cannot be rejected for the commitment treatment ( $p=7.8\%$ ), we can clearly reject it for all discretionary treatments ( $p<1\%$ ), and the direction is always negative, indicating under-prediction of inflation. Comparing the different treatments, we find that under commitment, the expectation bias is smaller than in all discretionary treatments ( $p<1\%$ ), under cheap talk, the bias is larger than in the other discretionary treatments ( $p<1.1\%$ ). PT, PT+CT, and ET produce similar biases ( $p>40\%$ ) and they are all larger than under baseline discretion ( $p<3\%$ ). The existence, direction and size of these expectation biases are surprising, and we will discuss some possible explanations below.

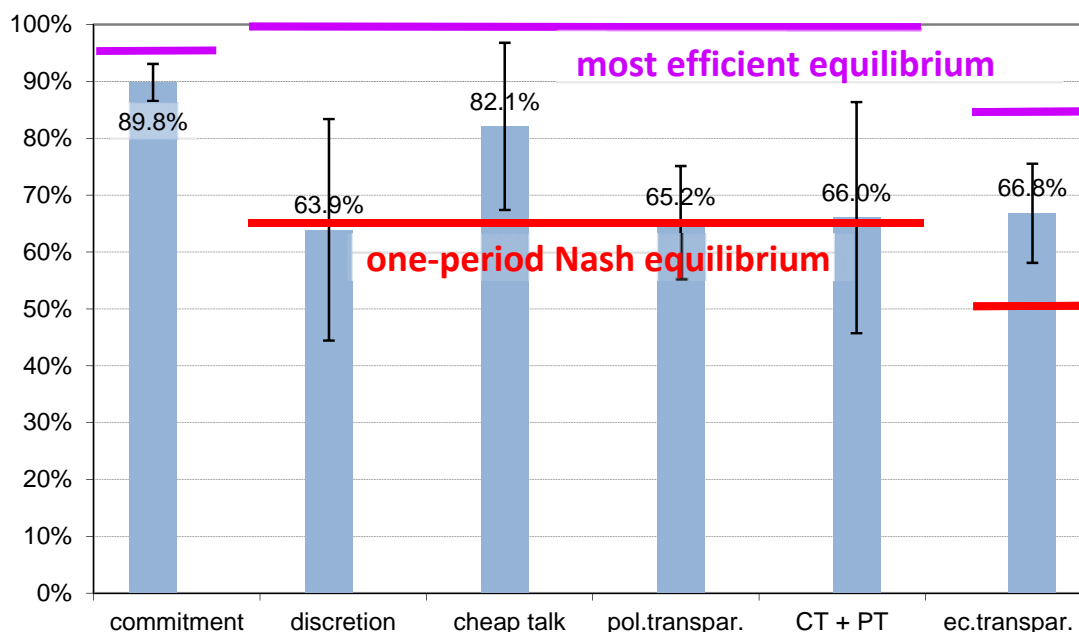
An immediate consequence of biased expectations, is that average unemployment is smaller than the NAIRU. Figure 3 shows the average final Container-1 amount that represents unemployment in our model. While the target value is 120, average unemployment in any rational expectations equilibrium (NAIRU) is 140. Since private sector expectations fall short of average inflation rates, the unemployment rate deviates from the natural rate towards the central banks' target rate (except for commitment). Under cheap talk, the effect is so strong that average unemployment is closer to target than to the natural rate.

**Figure 3: Average unemployment (final Container 1 amount)**



Besides the different inflation biases across treatments and the different abilities of central banks to stabilize employment, the systematic deviations of average unemployment from the natural rate provide a third and unexpected factor influencing central bank welfare. For testing Hypothesis 8, we use two different measures: we compare the actual payoffs of our central bankers as a measure of central bank welfare, but we also compare that payoff with the payoff that the central bank would have achieved in the Ramsey equilibrium had the central banker played an optimal response to shocks. The advantage of the second measure is that it eliminates fluctuations in payoffs stemming from shocks. The first measure, however, allows for a direct test of the point predictions arising from the various equilibria.

**Figure 4: Achieved welfare versus equilibrium welfare**



**Finding 3:** *In most discretionary treatments, average welfare is closer to the one-shot Nash equilibrium and significantly smaller than under commitment. Only cheap talk works as a substitute for commitment regarding welfare.*

Figure 4 shows that average welfare is below the welfare level associated with optimal policy in all treatments ( $p < 4\%$ ). However, since our subject central bankers are not perfect, they also make mistakes under commitment, so that the payoffs of A-players in this treatment are smaller than predicted by equilibrium ( $p < 1\%$ ). If we compare the achieved payoffs between different treatments, we cannot reject Hypothesis 8 for the cheap talk treatment. Here, the achieved payoffs are not smaller than under commitment ( $p = 23\%$ ), while they are significantly smaller for the other four discretionary treatments ( $p < 1.1\%$ ). Comparing the payoffs for cheap talk with the other discretionary treatments directly, the evidence is mixed: central bank payoffs are higher under cheap talk than for policy transparency ( $p = 2.1\%$ ) and economic transparency ( $p = 4.99\%$ ), but not significantly different from baseline discretion ( $p = 8.3\%$ ) and PT+CT ( $p = 13\%$ ). Comparing welfare with the predictions of the one-period Nash equilibrium, we can

clearly reject equality under cheap talk and economic transparency ( $p=1.6\%$ ), but not for the other discretionary treatments ( $p>80\%$ ).

Regarding Hypothesis 9, we can reject that central bank payoffs under economic transparency equal those under commitment ( $p<1\%$ ), but we cannot reject that they equal the payoffs in the baseline discretionary treatment ( $p=96\%$ ). For economic transparency, the one-shot Nash equilibrium and the most efficient equilibrium are both associated with lower payoffs than the corresponding equilibria under baseline discretion. This is because monetary policy cannot stabilize employment in equilibrium if its responses to supply shocks are anticipated. However, the forecasts of our B-players respond less to supply shocks than necessary to offset the responses by money supply, which results in some stabilization of output. In effect the stabilization of output is almost as good as under baseline discretion (see Table 4 below), so we find similar levels of central bank welfare in both treatments.

In order to test hypotheses regarding the players' responses to each other and to supply shocks, we report on treatment-specific, fixed effects regressions where the individual unit (for which fixed effects are allowed) is CB (Type A) subject  $i$  of matching group  $j$  in supergame  $k$ . The main regression specification for the central banker's behavior was:

$$m_t^i = \alpha + \delta_1 w_t + \delta_2 avgf_t + \beta_1 m_{t-1}^i,$$

where  $m_t^i$  is the CB player  $i$ 's money supply choice at time  $t$ , and  $w_t$  and  $avgf_t$  are, respectively, the supply shock and average inflation forecast of the private sector that CB player  $i$  faced at time  $t$ .<sup>18</sup> We impose the additional restriction that  $\delta_2 = 0$  for the commitment treatment since the central bank had to decide on  $m$  before knowing the private sector's average inflation forecast. We also include the lagged value of the CB's money supply decision,  $m_{t-1}^i$ . The regression results are reported in Table 2.

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<sup>18</sup> Similar results are obtained using an Arellano-Bond dynamic panel-data estimation procedure in place of our fixed effects panel data estimation.

**Table 2: Central Bank Behavior**

Treat. Parameter	Commitment	Discretion	Cheap Talk	Policy Transparency	CT + PT	Economic Transparency
$\alpha$	-37.01*** (10.77)	-7.72 (13.51)	-54.59*** (12.02)	-27.97 (19.25)	-25.28** (12.65)	-32.10*** (11.70)
$\delta_1$	0.41*** (0.07)	0.36*** (0.05)	0.54*** (0.06)	0.50*** (0.07)	0.47*** (0.06)	0.35*** (0.08)
$\delta_2$	-	0.15 (0.13)	0.50*** (0.09)	0.22 (0.20)	0.31*** (0.06)	0.55*** (0.10)
$\beta_1$	0.13 (0.09)	0.05 (0.07)	-0.03 (0.04)	0.01 (0.08)	-0.08* (0.05)	0.005 (0.04)
R <sup>2</sup>	0.25	0.39	0.61	0.24	0.32	0.39

Notes: \*\*\* significant at 1%, \*\* significant at 5%, \* significant at 10% levels; robust standard errors in parentheses

The estimated coefficient on the supply shock,  $\delta_1$ , is significantly positive in all treatments ( $p < 1\%$ ) indicating that central bankers are responding to these shocks in all six treatments. The significantly positive estimate for  $\delta_1$  in the commitment treatment is at odds with the equilibrium prediction that central bankers should *ignore* the supply shock altogether (provided that forecasters are rational). The estimates for  $\delta_1$  in four of the five discretionary treatments – all but the cheap talk treatment – are not significantly different from the estimated  $\delta_1$  for the commitment treatment, so that we cannot reject Hypothesis 1b, that in the repeated game, the CB responds to supply shocks as if s/he were operating under a commitment regime. In the five discretionary treatments, the estimates for  $\delta_1$  are significantly less than the equilibrium predictions (from Table 1) of  $2/3$  ( $p < 5\%$ ). We also find that central bankers respond to average inflation forecasts with positive  $\delta_2$  coefficients that are significantly different from zero in three of the five discretionary treatments and significantly less than the  $2/3$  prediction of the one-shot Nash equilibrium ( $p < 5\%$ ) in Treatments Discretion, Policy Transparency (PT), and cheap talk plus policy transparency (CT+PT). Hypothesis 2b, that  $\delta_1 = \delta_2$  in each of the five discretionary regimes, is rejected for the Treatment CT+PT according to an F-test ( $p < 5\%$ ). In the other four discretionary treatments, the same F-test indicates that we cannot reject the null that CB players are attaching approximately equal weight to supply shocks and inflation

expectations, ( $p > .05$ ) consistent with Hypothesis 2b. Finally, we note that the coefficient on the CB's lagged money choice,  $\beta_1$ , is not significantly different from zero, with the exception of the CT+PT treatment where this coefficient is marginally negative. We summarize the main findings of Table 2 as follows:

**Finding 4:** *A-players' responses to supply shocks are significantly positive in all treatments, contrary to the equilibrium prediction for the commitment regime. They are significantly lower than equilibrium predictions in all discretionary environments. Responses to inflation expectations are highest for the cheap talk and economic transparency treatments, where they are not significantly lower than equilibrium predictions. Lagged policy decisions do not seem to matter for current policy choices.*

We next turn to an analysis of the behavior of type B players (private sector agents). We estimate a regression of individual inflation forecasts,  $f_t^i$ , using treatment-specific information available to private sector agents when forming those forecasts including money supply,  $m_t$ , the CB's announcement,  $ann_t$ , the supply shock,  $w_t$ , lagged own expectations, the lagged own forecast error, and the lagged average forecast. While the lagged forecast error can identify eventual learning behavior, the coefficient on the lagged average forecast provides a measure of convergence in forecasts. Specifically, we report in Table 3 on a

$$f_t^i = \alpha + \delta_1 m_t + \delta_2 ann_t + \delta_3 w_t + \beta_1 f_{t-1}^i + \beta_2 \pi_{t-1} + \beta_3 avgf_{t-1},$$

where the individual unit (for which fixed effects are allowed) corresponds to type B subject  $i$  of matching group  $j$  in supergame (sequence)  $k$ . Results are displayed in Table 3

**Table 3: Private Sector Forecasts**

Treat. Parameter	Commitment	Discretion	Cheap Talk (1)	Cheap Talk (2)	Policy Transparency	CT + PT (1)	CT + PT (2)	Economic Transparency
$\alpha$	18.81*** (0.75)	13.97*** (2.79)	36.52*** (2.78)	29.28*** (5.30)	29.45*** (4.63)	46.29*** (4.03)	43.58*** (6.11)	-20.46*** (5.94)
$\delta_1$	0.96*** (0.02)	-	-	-	-	-	-	-
$\delta_2$	-	-	0.42*** (0.04)	-	-	0.18*** (0.03)	-	-
$\delta_3$	-	-	-	0.08*** (0.03)	-	-	0.05* (0.03)	0.52*** (0.04)
$\beta_1$	0.01 (0.04)	0.13** (0.05)	0.04 (0.05)	0.04 (0.05)	0.18** (0.07)	0.03 (0.05)	0.03 (0.05)	-0.05 (0.06)
$\beta_2$	0.05*** (0.01)	0.29*** (0.02)	0.13*** (0.02)	0.11*** (0.02)	0.14*** (0.02)	0.10*** (0.02)	0.08*** (0.02)	0.12*** (0.02)
$\beta_3$	-0.03 (0.04)	0.39*** (0.05)	0.09* (0.06)	0.15*** (0.06)	0.27*** (0.06)	0.17*** (0.06)	0.18*** (0.06)	0.17** (0.08)
R <sup>2</sup>	0.80	0.74	0.38	0.46	0.58	0.41	0.52	0.25

Notes: \*\*\* significant at 1%, \*\* significant at 5%, \* significant at 10% levels; robust standard errors in parentheses

In the Commitment treatment, theory predicts that  $\delta_1 = 1$ , and while we can reject this prediction ( $p < 5\%$ ), the actual estimate (.96) is very close to 1. Under economic transparency, consistent with Hypothesis 5, subjects respond to supply shocks, but the coefficient,  $\delta_3$ , is significantly smaller than the theoretical prediction of 2 ( $p < 1\%$ ). Note that for both cheap-talk treatments, the response of inflation forecasts to announcements made by the central bank is positive and significant as indicated by the estimate for  $\delta_2$ . If cheap talk is combined with policy transparency, the announcement coefficient is reduced by more than 50%. This shows that our subject central bankers are successful in affecting expectations by non-binding announcements, in particular when these announcements cannot be fully evaluated by forecasters against actual decisions by the central bankers as in the cheap talk treatment. This finding may come as a surprise and it explains why we observe the largest bias between actual and expected inflation in the cheap-talk



treatment without policy transparency. We will further analyse CB announcements below, to determine whether central bankers try to exploit their effect on expectations.

In a second specification for the two cheap talk treatments (2) as reported in Table 3, we also explore whether unobserved supply shocks affect individual forecasts via CB announcements. We do this by setting  $\delta_2 = 0$  and adding the unobserved (in these treatments) supply shock,  $w_t$ . We find that in both cheap talk treatments, the supply shock does affect forecasts, as evidenced by the positive and significant coefficient estimate for  $\delta_3$  suggesting that the CB *is* communicating this information via its announcements, contrary to Hypothesis 5. By contrast in the economic transparency treatment, private sector forecasts *should* condition on the supply shock with weight 2 (see Table 1) but the estimated weight reported in Table 3 is only about one quarter of this prediction. Summarizing we have:

**Finding 5:** *Consistent with theory, under commitment, forecasts are closely aligned with the choices of A-players. Inconsistent with theory, in the cheap talk treatments, forecasts respond to policy announcements and, these announcements reveal information about supply shocks. The response of inflation forecasts to supply shocks in the economic transparency treatment is about 25% of the predicted level.*

Table 3 reveals that in all treatments, subjects' inflation forecasts respond to lagged inflation as evidenced by the significantly positive coefficient estimates for  $\beta_2$ , which suggests evidence for adaptive learning rules as has been found in other studies where subjects are tasked only with forecasting an endogenously determined variable (for a survey of such learning to forecast experiments, see Hommes 2011). Numerically, this effect is smallest for commitment and highest for the pure discretionary treatment. Since  $\beta_3$  is significantly positive in all discretionary treatments, individual forecasts converge over time.<sup>19</sup>

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<sup>19</sup> Lagged own and average forecasts are highly correlated, in particular under commitment. We used a 2-step GLS estimate as a robustness check, and the qualitative results were the same. An Arellano-Bond dynamic panel-data estimation procedure, however, delivered mostly insignificant coefficients for lagged own and average forecasts, while the other variables generally kept their significance levels.

If forecasters are learning, it is puzzling that their expectations are systematically biased towards too low an inflation rate, which runs counter to Hypotheses 3 and 4. Nevertheless, it may be that this bias becomes smaller over time. In order to address that question, we analyze the data on expectation bias separately for the first and last 15 periods of each treatment<sup>20</sup> and focus on the magnitude of the bias in expectations and on the welfare effects that are heavily influenced by average unemployment deviating from NAIRU for biased expectations. This analysis is presented in Figures 5 (expectation bias) and 6 (welfare).<sup>21</sup> We find that the expectation bias is indeed smaller for the later periods than for the first periods in all discretionary treatments (see Figure 5), but this difference is significant only for the baseline discretionary treatment and for the PT+CT treatment ( $p < 2\%$ ; in other treatments:  $p > 10\%$ ). In the CT treatment (and only there), the average money supply is significantly higher in the later periods than in the early periods ( $p < 1\%$ ).<sup>22</sup> Rising average inflation and unemployment reduce the achieved welfare levels in the CT treatment (see Figure 6): the average welfare level in the last 15 periods is at 72.8% of the first best. This is smaller than under commitment ( $p = 8.3\%$ ) and the differences between CT and the other four discretionary treatments or the one-shot Nash equilibrium are not significant anymore ( $p > 19\%$ ). For CT, the difference is highly significant ( $p < 1\%$ ). For all other treatments, the differences are not significant ( $p > 19\%$ ). Summarizing, our main result from examining expectations and welfare over time is:

**Finding 6:** *The expectation bias in favor of low inflation diminishes with experience in all discretionary treatments. Cheap talk initially raises welfare to levels approximating the first best, but this effect is only temporary (first 15 periods).*

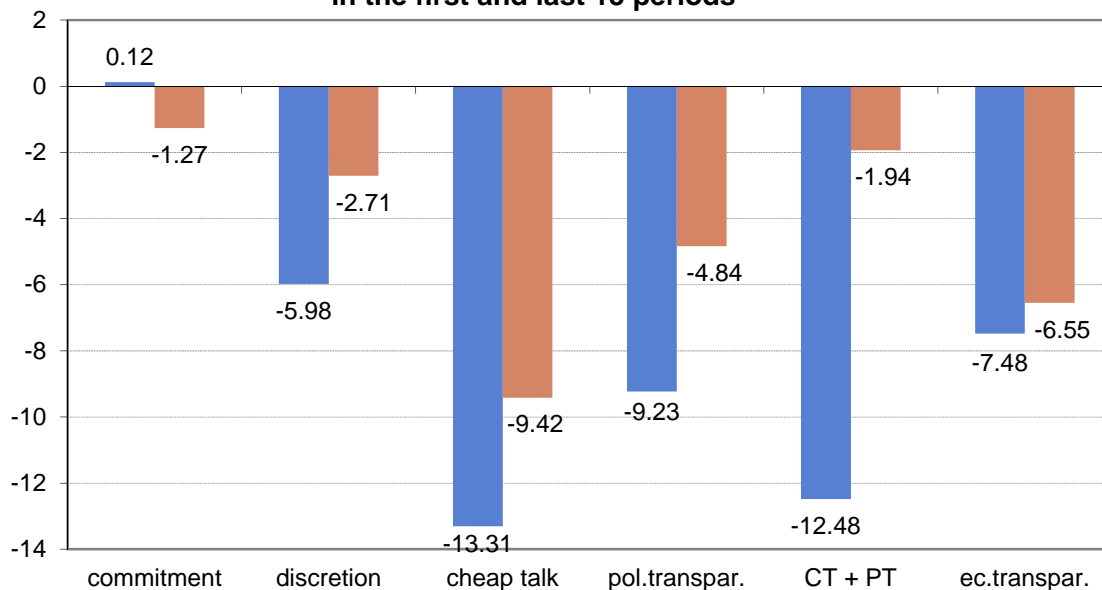
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<sup>20</sup> In sessions combining policy transparency with cheap talk, we had only 25 to 32 periods in total due to the extra input and feedback required by this treatment. Thus, for the CT+PT treatment sessions, we took the first and last 12 periods instead. The other sessions had 30 to 49 periods.

<sup>21</sup> In Figures 5 and 6, the left (blue) bars visualize results from the first periods, the right (brown) bars visualize results from the last periods of each treatment

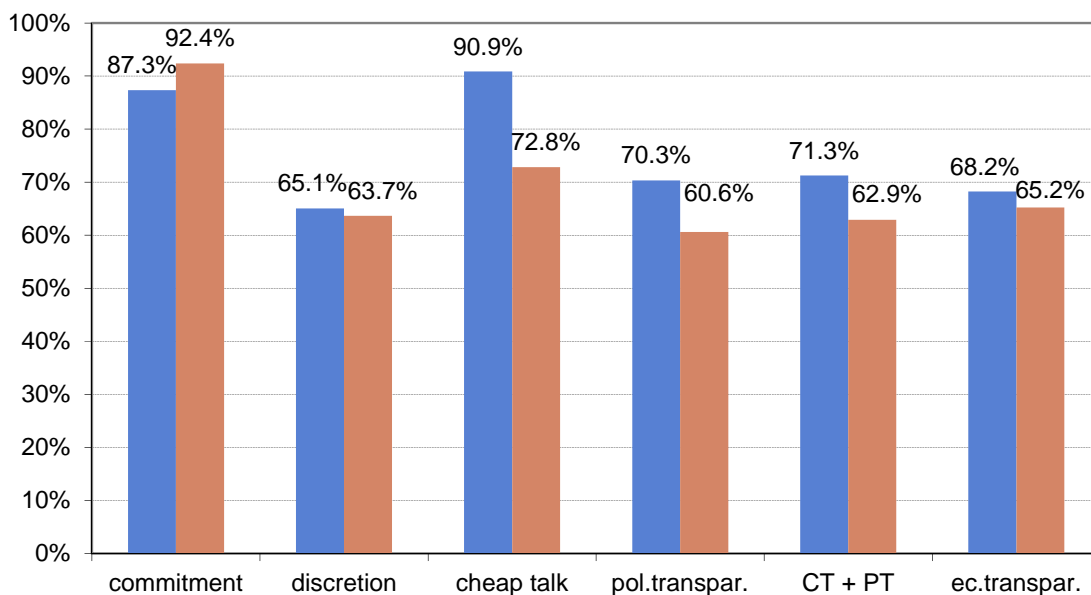
<sup>22</sup> We observe a significant reduction in money supply under commitment ( $p = 5.5\%$ ). In other treatments, there are no significant differences between money supply in the first and last periods ( $p > 19\%$ ).

**Figure 5: Expectation bias (avg.forecast - m - 20)  
in the first and last 15 periods**



Note: In CT+PT we compared the averages from the first and last 12 periods.

**Figure 6: Welfare in the first and last 15 periods**



Note: In CT+PT we compared the averages from the first and last 12 periods.

Next, we look at the stability of unemployment across treatments. Due to the combined responses of monetary policy, announcements, and expectations (when it applies) to supply shocks, there may be significant differences in the stability of unemployment across treatments. Just looking at the standard deviations of unemployment, we find that it is significantly larger than predicted by theory in all treatments. In fact, our subject central bankers even contribute to fluctuations in unemployment, because standard deviations are usually higher than they would be for a constant money supply. Table 4 displays the standard deviation of unemployment, averaged over all matching groups for each treatment along with equilibrium predictions, repeated here from Table 1.

**Table 4: Standard Deviation of Unemployment**

	Commitment	Discretion	Cheap Talk	Policy Transparency	CT + PT	Economic Transparency
St. Dev. of $u_t$	16.56	19.48	17.73	18.66	19.03	20.55
Std. error	(1.35)	(2.58)	(2.51)	(3.79)	(2.94)	(2.15)
equilibrium	16.33	12.17	12.17	12.17	12.17	16.33

Note: Std. error is the standard error of the “standard deviation of unemployment” across matching groups.

Two-sided Wilcoxon matched pairs test show that fluctuations in unemployment are significantly larger than the equilibrium predictions under the baseline discretion treatment ( $p=2.3\%$ ), economic transparency ( $p<1\%$ ), and the combination of cheap talk and policy transparency ( $p=3.9\%$ ). In the other treatments, there is no significant difference. The reason for the high variation of unemployment in spite of central bankers responding to supply shocks in the right direction are (i) central bankers are changing over time and different central bankers are pursuing different policies, (ii) forecasters and their forecasts are changing over time and fluctuating expectations contribute to fluctuations in employment, even if central bankers respond to expectations in an optimal way,<sup>23</sup> and (iii) as we have found, central bankers respond with suboptimal coefficients to supply shocks and expectations, so that the combination of both may leave

<sup>23</sup> Note that expectations are constant in equilibrium (except for economic transparency) but fluctuate quite a lot in the experiment. An increase in expected inflation has the same effect on the economy as an adverse supply shock.

unemployment with more fluctuations as under constant expectations and constant money supply. With specific regard to Hypothesis 6, we have the following:

**Finding 7:** *Contrary to Hypothesis 6, unemployment (output) volatility is not generally lower in the commitment and economic transparency treatments as compared with the other discretionary treatments.*

Support for Finding 7 comes from two-sided Mann-Whitney-U tests which indicate that unemployment fluctuates less under commitment than under the baseline discretion ( $p=2.1\%$ ) and economic transparency ( $p<1\%$ ) treatments. Cheap talk also leads to lower fluctuations than economic transparency ( $p=2.1\%$ ). The other pairwise comparisons do not yield significant differences ( $p>10\%$ ). It is remarkable that discretionary monetary policy leads to higher fluctuations of employment than commitment (rejecting Hypothesis 6). The reason is that in the commitment regime, inflation expectations and the money supply move almost 1 to 1 (see the coefficient  $\delta_1$  in Table 3). Hence, the only remaining impact on employment comes from exogenous shocks. In the discretionary treatments, changing CB policies and fluctuations of expectations that are not well coordinated with monetary policy lead to higher and unsystematic fluctuations between actual and expected inflation and work to destabilize employment. This result was also surprising to us. It provides a strong argument in favor of rule-based monetary policy. The fact that cheap talk leads to the second lowest standard deviation of employment indicates that announcements could have a small stabilizing effect. Of course, this requires that actual policy is correlated with announcements, as is indeed the case (as we will show below). However, since the differences in the standard deviation of  $u_t$  between cheap talk and most other treatments are not significant, we cannot draw any conclusions for the eventual stabilizing effects of cheap talk. This topic requires further exploration.<sup>24</sup>

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<sup>24</sup> Ahrens et al. (2017) are currently working on a comparable experiment in which they focus on the effects of forward guidance.

**Table 5: Standard Deviation of Inflation**

	Commitment	Discretion	Cheap Talk	Policy Transparency	CT + PT	Economic Transparency
St.Dev. of $\pi_t$	18.86	19.94	19.60	18.44	17.93	20.28
Std. error	(2.79)	(2.10)	(2.69)	(2.63)	(1.14)	(2.13)
Equilibrium	11.55	13.88	13.88	13.88	13.88	25.82

Note: Std. error is the standard error of the “standard deviation of inflation” across matching groups.

Volatility of inflation is about the same across all treatments (see Table 5). In the treatment CT+PT, it is significantly smaller than for the baseline discretionary treatment ( $p=4.0\%$ ) or economic transparency ( $p=1.4\%$ ). PT also leads to smaller inflation volatility than ET ( $p=5.2\%$ ). All other pairwise comparisons are insignificant ( $p>0.17$ ). With the sole exception of the ET treatment, inflation volatility is significantly greater than in rational expectations equilibrium ( $p<1\%$ ); under ET, inflation volatility is smaller than predicted ( $p<1\%$ ). The high level of inflation volatility can be explained once more by central bankers pursuing different policies over time. Under economic transparency, inflation volatility is predicted to be higher, because in equilibrium, private sector expectations respond to the shock so strongly that the CB has no incentive to deviate. The previous regressions, however, have shown that inflation expectations and monetary policy respond to supply shocks with coefficients that are much smaller than in equilibrium and the monetary policy response under economic transparency is rather comparable to the other discretionary treatments. For this reason, the volatility of inflation under economic transparency is not significantly higher than in those other treatments and, thus, lower than predicted by equilibrium theory. In the literature, it has been argued that imprecise public announcements may raise the volatility of aggregate prices (Amato and Shin, 2003). The evidence in our experiment does not support this view, but the structure of our model differs from Amato and Shin in that our forecasters have no incentives to coordinate their forecasts.

The dispersion of individual forecasts within a group of forecasters provides a good measure for the overall transparency of the policy regime. If CB behaviour is fairly predictable, then individual forecasts should be close to one another. In equilibrium, all B-players should have the same expectations leading to a zero dispersion of individual forecasts independent from the treatment. We find, however, contrary to Hypothesis 4, that there are significant differences in this dispersion across treatments (see Table 6).

**Table 6: Average Dispersion of Forecasts Within Groups and Forecasters' payoffs**

	Commitment	Discretion	Cheap Talk	Policy Transparency	CT + PT	Economic Transparency
St.dev. ( $\pi_t^i t$ )	5.56	8.94	11.57	9.16	11.09	12.28
Std. Error	(1.66)	(1.49)	(2.34)	(2.21)	(2.25)	(1.65)
Avg. Payoff of B-players	3799	3537	3426	3515	3475	3451

In the commitment treatment, the dispersion of individual forecasts is smaller than in all discretionary treatments ( $p < 1\%$ ). Within discretionary treatments, the dispersion is higher when forecasters get *more* information, as under cheap talk, CT+PT, or economic transparency. The differences between dispersion in these treatments vis-à-vis the baseline discretionary or policy transparency treatment are all significant ( $p < 10\%$ ), while differences within this group or between baseline and policy transparency are not significant ( $p > 10\%$ ). Without these signals, private sector agents can more easily coordinate on a common expectation. These findings contrast with empirical results by Ehrmann et al. (2012), who “find that central bank transparency and communication (...) reduce the dispersion of professional forecasters’ views” (p.1019). Hubert (2015), however, attributes the impact of central bank communication on professional forecasts to their policy dimension rather than their economic accuracy.

Since our B-players are paid according to forecast accuracy, their payoffs measure the quality of their forecasts. Under commitment, these payoffs are greater than in all discretionary treatments ( $p < 1\%$ ). We find no significant differences in B-players’ payoffs between discretionary treatments ( $p > 10\%$ ), except that payoffs under economic transparency are somewhat smaller relative to baseline discretion ( $p = 7\%$ ). Summarizing, we have:

**Finding 8:** *Inconsistent with Hypothesis 4, distribution of individual forecasts around the average inflation forecast differs across treatments.*

Why don’t B-type subjects use cheap-talk announcements or information about supply shocks to better coordinate their expectations than in the baseline treatment without this information? The data indicate that

subjects disagree in how actual money supply is related to announcements or supply shocks. Different perceptions of CB credibility create a huge dispersion in forecasts. Further, under economic transparency, subjects can have different expectations about the CB's responses to supply shocks. If these expectations diverge, the posterior beliefs after learning the supply shock may be more dispersed than prior beliefs without such information. While in theory, economic transparency raises forecasters' payoffs compared to baseline discretion, we observe just the opposite in our experimental data.

As cheap talk seems to have a remarkable impact on the economies, we also analyse how the cheap-talk messages depend on various explanatory variables. Here, we use three different specifications which are versions of the regression model:

$$ann_t^i = \alpha + \delta_1 w_t + \beta_1 ann_{t-1}^i + \beta_2 (avgf_{t-1} - ann_{t-1}^i) + \beta_3 m_{t-1}^i + \beta_4 \pi_{t-1},$$

where the variable names are as described earlier. Table 7 reports on fixed effects regression results where the individual unit is as described previously for Table 2.

**Table 7: Cheap Talk Announcements**

Treat. Parameter	Cheap Talk (1)	Cheap Talk (2)	Cheap Talk (3)	CT + PT (1)	CT + PT (2)	CT + PT (3)
$\alpha$	-26.43*** (8.16)	-28.72*** (8.82)	-23.54*** (9.02)	2.45 (12.89)	18.75 (16.19)	12.46 (14.97)
$\delta_1$	0.28*** (0.06)	0.28*** (0.06)	0.28*** (0.06)	0.19** (0.08)	0.17** (0.09)	0.20** (0.09)
$\beta_1$	0.02 (0.10)	-	-	0.04 (0.10)	-	-
$\beta_2$	-	0.05 (0.08)	0.04 (0.08)	-	-0.20* (0.11)	-0.20* (0.11)
$\beta_3$	0.05 (0.07)	0.06 (0.06)	-	-0.19 (0.07)	-0.26*** (0.07)	-
$\beta_4$	-	-	-0.02 (0.04)	-	-	-0.15*** (0.05)
$R^2$	0.08	0.02	0.01	0.04	0.08	0.11

Notes: \*\*\* significant at 1%, \*\* significant at 5%, \* significant at 10% levels; robust standard errors in parentheses



Note first, and most importantly, that for both cheap talk treatments, and all regression specifications, the CB's announcements vary positively and significantly with the supply shocks as evidenced by the significantly positive estimates for  $\delta_1$ . Thus, these CB announcements are informative about the current state of fundamentals, and private sector forecasters can extract some information from them. However, given the low  $R^2$  and the low coefficient estimates by which CB-players respond to these supply shocks, the forecasters should put a very low weight on these announcements, which is indeed in line with the low weights given to CB announcements as reported in the regressions reported in Table 3. Notice second that there is no persistence in announcements, as evidenced by the insignificant coefficient attached to  $\beta_1$ . Finally, the significantly negative coefficient estimates for  $\beta_2$  in the CT+PT treatment suggest that the greater the departure of lagged inflation forecasts from the lagged announcements, the more the CB attempts to dampen down inflationary pressure by announcing an even lower policy choice for  $m_t$ . Eventually, it seems, the private sector learns to ignore these cheap talk messages because of the evident disconnect between the CB announcements and actual inflation as revealed in Figure 1, but this does not prevent the CB from trying to use cheap talk announcements to influence private sector expectations. Summarizing, we have:

**Finding 9:** *Cheap talk announcements by CB players are informative as they convey information about supply shocks. When there is also policy transparency, CB players react to departures of inflation forecasts from lagged announcements by lowering their announced policy for  $m_t$ .*

## 6. Conclusion

Central bankers operate in a discretionary world where they face a trade-off between credibility in stabilizing inflationary expectations on the one hand and flexibility in response to economic shocks on the other. In this paper we have posed the question of whether a balance can be found between these twin objectives in a repeated game setting where reputational concerns might serve as a substitute for commitment so that welfare under discretionary policy might approximate or even exceed the levels attainable under a full commitment regime. We addressed this question using a version of the Barro-Gordon

(1983ab) monetary policy game model and controlled laboratory experiments with paid human subjects serving in the role of private sector agents forecasting inflation or as central bankers facing the policy trade-off between credibility and flexibility. The advantage of our laboratory approach is that we have good control over the incentive structure and information available to all actors so that we can formulate crisp equilibrium predictions about the type of behavior we should observe under commitment and discretionary regimes. This same level of control is not available using field data so that an evaluation of whether central banks are behaving in a discretionary repeated game setting as if they had a commitment is not really testable in the field.

In answer to the question we posed, we can unambiguously reject the notion that reputation in the discretionary repeated game setting leads to outcomes approximating the first best, Ramsey solution in favor of the alternative that behavior is closer to the predictions of the one-shot Nash equilibrium involving higher inflation and lower welfare. Importantly, as we also study the full commitment regime in the laboratory, we are able to show that there are important policy and welfare differences between the commitment and discretionary regimes. In addition, we have considered several augmented versions of our baseline discretionary policy regime that allow central bank cheap talk about policy intentions, ex-post transparency about policy actions, both cheap talk and policy transparency and economic transparency. Among these mechanisms, only cheap talk served to raise welfare to levels approximating those achieved under the commitment regime, as central bankers tried to convince private sector agents that they would keep inflation low. However even this effect diminished over time, as private sector agents learned to ignore the CB's cheap talk messages. We conclude that the discretionary regimes of our laboratory study are indeed welfare reducing relative to the commitment regime, and that flexibility in responding to economic shocks and expectations appears to dominate any longer-term concerns about the credible maintenance of low inflationary expectations. This welfare conclusion is further supported by the observation that private sector forecasters earn the highest payoffs under a commitment regime.

It is remarkable that we do not find a trade-off between credibility and flexibility. Indeed, we find that discretionary policy regimes which allow for the stabilization of employment actually lead to *higher* variations in employment than under a perfectly credible commitment regime where stabilization is not possible, although central bankers *do* make an attempt to stabilize the impact of supply shocks in all regimes. As we have seen, there are several reasons for this divergence between theory and outcomes. First, central-bank responses to shocks are smaller than optimal in all of our discretionary treatments, diminishing the stabilizing role of those more flexible discretionary regimes. Second, changes in strategies by different central bankers provide an additional source of strategic uncertainty that is not addressed by the theory. As this strategic uncertainty is likely to carry over to the field, we conclude that central banks would do well to follow strict rules and make them common knowledge to private sector forecasters. Any changes in central bank strategies should be communicated thoroughly and before they are implemented, to minimize strategic uncertainty. Third, forecasters are unable to effectively use the additional information provided by central bank announcements or about shocks (under economic transparency) to improve their forecasts. The reason is that forecasters disagree about the quality of announcements and the likely response of central bankers to supply shocks. Unlike all theoretical predictions, this strategic uncertainty raises forecast errors relative to the baseline discretionary regime in which forecasters do not get any additional information regarding the realization of the current period's random variables. From the latter result we conclude that CBs should avoid providing ambiguous signals or information about fundamentals that leave the private sector puzzled about the likely response of inflation to those fundamentals.

We expect that our experimental findings carry over to the “real world” since the incentives and uncertainties that our subjects faced also approximate those faced by real central bankers and private sector agents. For instance, we note that there is corroborating empirical evidence that central banks publish inflation forecasts to strategically manipulate private inflation forecasts just as our human subject central bankers do in the treatments with cheap talk (Gomez-Barrero and Parra-Polania, 2014). While it is possible that well-intentioned, real world central bankers, aware of the time inconsistency problem of monetary

policy, can learn to implement the optimal policy – in the words of McCallum (1995), they “just need to do it” – the long debate about rules versus discretion in central bank policy suggests that there are also doubts about the ability of such real world central bankers to effectively manage the trade-off between credibility and flexibility. The experimental evidence that we have presented in this paper provides further evidence that such doubts may be warranted.

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## Appendix A: Ramsey solution

The efficient linear solution  $m_t = \pi^* + \frac{c}{b+c^2} w_t$  can be formally derived by minimizing the central bank objective by a monetary policy rule  $m(w_t)$  for which  $E(\pi_t) = \pi^*$ .

$$\begin{aligned}
 & \operatorname{argmin}_{\{m_t\}} E \sum_{t=0}^{\infty} \delta^t [b(\pi_t - \pi^*)^2 + (u_t - u^*)^2] \\
 &= \operatorname{argmin}_{\{m_t\}} E \sum_{t=0}^{\infty} \delta^t [b(m_t + v_t - \pi^*)^2 + (u_n - c(m_t + v_t - \pi^*) + w_t - u^*)^2] \\
 &= \operatorname{argmin}_{\{m_t\}} \sum_{t=0}^{\infty} \delta^t [bE(m_t^2) - 2bE(m_t)\pi^* + c^2 E(m_t^2) - 2cE(m_t)(u_n - cv_t + c\pi^* + w_t - u^*)] \\
 &= \operatorname{argmin}_{\{m_t\}} \sum_{t=0}^{\infty} \delta^t [(b + c^2)E(m_t^2) - 2bE(m_t)\pi^* - 2cE(m_t)(u_n + c\pi^* - u^*) - 2cE(m_t)w_t]
 \end{aligned}$$

Let us assume a linear rule  $m_t = \pi^* + \alpha w_t$ . Then the optimal coefficient  $\alpha$  is

$$\begin{aligned}
 & \operatorname{argmin}_{\alpha} \sum_{t=0}^{\infty} \delta^t [(b + c^2)\alpha^2 E(w_t^2) - 2c\alpha E(w_t^2)]. \\
 & \Rightarrow \sum_{t=0}^{\infty} \delta^t [(b + c^2)\alpha E(w_t^2) - cE(w_t^2)] = 0 \\
 & \Leftrightarrow (b + c^2)\alpha E(w_t^2) - cE(w_t^2) = 0 \Leftrightarrow \alpha = \frac{c}{(b+c^2)}
 \end{aligned}$$

The Ramsey rule is the linear policy function that avoids an inflation bias and responds to supply shocks such that the impact is optimally distributed on employment and inflation. The Ramsey rule can be sustained as an equilibrium, if there is an expectation formation process, for which the central bank has no incentive to deviate from Ramsey.

## **Appendix B: Instructions Used in the Baseline, Discretionary Treatment.**

The instructions for the other five treatments reported in the paper are similar and can be viewed at: <http://www.socsci.uci.edu/~duffy/CBExperiment/>

### **Instructions**

#### **1. Overview**

Welcome to this experiment in the economics of decision-making. Please read these instructions carefully as they explain how you earn money from the decisions you make in today's experiment. There is no talking for the duration of today's session. If you have a cell phone, please turn the ringer off.

Today's session consists of a number of "sequences". Each sequence consists of a number of "rounds". At the start of each sequence the computer program will randomly assign all participants to a 5-member group. All random groupings of 5 participants are equally likely. Once you are assigned to a 5-member group, you will play all rounds of the sequence with the same 4 other members of your 5-member group. At the start of each new sequence, the computer program will again randomly assign players to 5-member groups. Your interactions with other participants is always anonymous; you will not be informed of the identity of any group member in any sequence played, nor will they be informed of your identity, even after today's session is over.

Prior to the first round of each new sequence, the program randomly selects one member of your 5-member group and assigns that person the role of Player A. The other 4 members of your group are assigned the role of Player B. You and the other members of your group will remain in the same role of Player A or Player B for all rounds of the sequence. At the start of each new sequence, the computer program will once again assign roles randomly among the members of your new 5-member group, and you will remain in your new role for the duration of that new sequence.

#### **2. The decisions to be made**



Imagine there are two containers labeled Container 1 and Container 2. At the start of each round, Container 1 holds  $W_0$  gallons of water while Container 2 is empty.

In each round, the four Player Bs in each group move first. Each Player B submits his or her forecast as to how many gallons of water there will be in Container 2 at the *end* of the round.

After all Player Bs have made their forecasts, the computer program calculates the average of the four Player B forecasts, which we denote by  $af$ . This average forecast is added to the amount of water in Container 1 so that the total amount of water in Container 1 is now  $W_0 + af$ .

Next, the Player A in the group learns both  $W_0$  and  $af$  and thereby the total amount of water in Container 1. Then, the Player A can move from 0 to 80 gallons of water from Container 1 to Container 2. Denote the amount moved by  $M$ .

In addition, there is a random, uncontrolled flow of water,  $V$ , from Container 1 to Container 2 that Player A does not know about when choosing  $M$ . Thus, the final amount of water in Container 2 is  $M + V$ .

### 2.1. Specific details

The initial water level in Container 1,  $W_0$ , is a random variable. For each round of a sequence, the computer program draws a value of  $W_0$  randomly and independently from a **uniform distribution over the interval [120, 160]**. This means that the minimum possible value of  $W_0$  is 120 and the maximum possible value of  $W_0$  is 160. All numbers between 120 and 160 inclusive have an equal chance of being drawn, so the expected value of  $W_0$  is 140.

In each round, the four Player Bs in each group move first. Each must submit their own forecast,  $f$ , of the final amount of water that will be in Container 2 at the end of the round. Recall that Container 2 is initially empty. Forecasts may range from 0 to 120 gallons of water inclusive in Container 2. Player Bs should type their forecast in the blue input box on their decision screen when prompted. Click the red Submit button when satisfied with your choice.

After all four Player Bs have entered their forecasts, the computer program calculates the *average value of the four forecasts*. Let us denote this average forecast by  $af$ . Then,  $af$  gallons of water are added to Container 1. Thus, the average forecast increases the amount of water in Container 1.

The total amount of water in Container 1 is now  $W_0 + af$ .

Note that Player Bs do not precisely know the value of  $W_0$  nor do they know  $af$ . They *do know* that  $W_0$  is a uniform random draw from the interval [120, 160] and they do know their own forecast,  $f$ .

Next, Player A alone is informed of the value of  $af$  for the round. In addition, Player A learns this round's value of  $W_0$  and is told the amount of water in Container 1,  $W_0+af$ .

*After* observing the values of  $af$  and  $W_0$  and the total amount of water in Container 1, the Player A in each group must decide how much water to move from Container 1 to the empty Container 2. Player A can move up to 80 gallons of water inclusive from Container 1 to Container 2 in each round. Let us denote by  $M$  the amount of water *moved* by Player A from Container 1 to Container 2. Player A should type his or her choice for  $M$  in the blue input box on their decision screen when prompted. Click the red Submit button when satisfied with your choice.

In addition to  $M$ , there is a random, uncontrolled flow of water from Container 1 to Container 2. This uncontrolled flow of water is another random variable, denoted by  $V$ . The computer program draws the value of  $V$  randomly from a uniform distribution over the interval [0, 40], which means that the minimum possible value of  $V$  is 0 and the maximum possible value of  $V$  is 40. All numbers between 0 and 40 inclusive have an equal chance of being drawn, so the expected value of  $V$  is 20. Player A *does not know*  $V$  when deciding how much water to move,  $M$ ; the uncontrolled flow,  $V$ , is determined only *after* Player A's choice of  $M$  has been made. It follows that:

The final amount of water in Container 1 is:  $W_0 + af - M - V$ .

The final amount of water in Container 2 is  $M + V$ .

Participants' payoffs depend on the final amounts of water in Containers 1 and 2 as described in the next section.

## 2.2. Payoffs for the round

If you are a Player A, the final amounts of water in both Containers 1 and 2 are used to determine your payoff in points for each round according to the formula:

$$\text{Player A Points} = 6000 - 2 (\text{Final Container 1 amount} - 120)^2 - (\text{Final Container 2 amount} - 40)^2$$

For your convenience, a non-exhaustive table of values for Player A's payoff in points is given in Table A as a function of the final water levels in Containers 1 and 2. Notice that Player A's maximize their payoff when the final amount of water in Containers 1 and 2 are as close as possible to 120 and 40, respectively, and that deviations in the final Container 1 water amount from 120 are 2 times more costly than are deviations in the final Container 2 water amount from 40.

If you are a Player B, only the final amount of water in Container 2 matters for your payoff in points. Specifically, your payoff in points for each round is given by the formula:

$$\text{Player B Points} = 4000 - (f - \text{Final Container 2 amount})^2$$

Recall that  $f$  denotes a Player B's *own* forecast for the round and *not* the average forecast,  $af$ . For your convenience, a non-exhaustive table of values for Player B's payoffs in points is given in Table B as a function of the difference,  $f - \text{Final Container 2 amount}$ . Notice that Player B's maximize their payoff when  $f = \text{Final Container 2 water amount}$ .

## 2.3. Feedback and record keeping at the end of each round.

At the end of each round, Player As will be reminded of  $W_0$ ,  $af$  and their choice of  $M$ . Player As will then learn of the value of the uncontrolled water flow from Container 1 to Container 2,  $V$ , and the final amount of water in Container 1 ( $W_0 + af - M - V$ ) and in Container 2 ( $M + V$ ). Finally, Player A's will be told their own payoff in points for the round and their cumulative point total for the sequence.

At the end of each round, Player Bs will be reminded of their forecast,  $f$ , and learn the average forecast,  $af$ , by all Player Bs in their group. Player Bs will then learn the value of  $W_0$  (initial water in Container 1), and the sum,  $W_0 + af$ , which is the amount of water in Container 1 *before* Player A's choice of  $M$ . Player Bs will *not* learn the amount of water the Player A chose to move from Container 1 to Container 2,  $M$ , nor will they learn the value of the uncontrolled water flow from Container 1 to Container 2,  $V$ , but they will learn the final amount of water in Container 1 ( $W_0 + af - M - V$ ) and the final amount of water in Container 2 ( $M + V$ ). Finally, Player Bs will be told the difference between their forecast  $f$ , and the final amount of water in Container 2, their own payoff in points for the round and their cumulative point total for the sequence.

Following revelation of this information, the round is over. Please record the results of the round on your record sheet under the appropriate headings. When you are done recording this information press the Continue button. The sequence may or may not continue with a new round, depending on the random number drawn. If a sequence continues, the procedures will be the same as above. Following the first round of a sequence, all players will see at the bottom of their screens, a history of past final amounts of water in Containers 1 and 2 for the five-person group they were in along with their own payoff in points for each round and their cumulative payoff in points from all rounds played in a given sequence.

### **3. When does a sequence of rounds continue and when does it end?**

At the end of each round, the computer program will randomly draw a number (an integer) between 1 and 6, inclusive. All numbers, 1,2,3,4, 5 and 6 have an equal chance of being drawn; it is like rolling a six-sided die. The number drawn will be displayed on your computer screen. If the number chosen is 1,2,3,4 or 5, the sequence will continue with a new round. If a 6 is chosen, the sequence will end. Thus, there is a 5 in 6 (83.33 percent) chance that a sequence will continue from one round to the next and a 1 in 6 (16.67 percent) chance that the current round will be the last round of the sequence.

If a sequence ends, then, depending on the time available, a new sequence may then begin. At the start

of each new sequence you would be randomly formed into new 5-member groups. One member of each group would be randomly chosen to play the role of Player A. The other four members would be assigned the role of Player B. These roles would again remain fixed for the duration of the new sequence.

If, by chance, the final sequence has not ended by the three-hour time period for which you have been recruited, we will schedule a continuation of that final sequence for another time in which everyone here can attend. You would be paid based on your cumulative point total for one randomly selected sequence that finished in today's session and you would receive a further payment following completion of the final sequence in a continuation sequence, as discussed below.

#### **4. Earnings**

If, as we expect, today's session ends within the 3-hour time period for which you have been recruited, then your payoff will depend on the total number of points you earned in a maximum of two of the sequences that were played in today's session. Specifically, if only one sequence was played, then your point total for today's session will equal your point total from that sequence. If two or more sequences have been played, then your point total for today's session will be the sum of your cumulative point totals from *two* sequences. If more than two sequences were played, then one sequence chosen for payment will be the sequence in which you earned the highest payoff. The other sequence will be randomly chosen from among all sequences played in today's session. Your session point total from the chosen sequence(s) will be converted into dollars at the rate of 2000 points = \$1.00 (or 20 points = 1 cent). Clearly, the more points you earn the higher is your dollar payoff. Since you don't know in advance which sequence(s) will determine your final payoff, you will want to do your best in every sequence. If, as mentioned above, the final sequence does not end within the 3 hour time period for today's session, then you would be paid for one randomly chosen sequence that did end during today's session (provided that event occurred) and following completion of the final sequence in the later, continuation session, you would also be paid for the sequence in which you earned the highest payoff.

In addition to your dollar earnings from the two sequences chosen for payment, you begin each sequence with 5000 points (\$2.50). The 5,000 initial endowment of points will show up in your cumulative point total for each sequence. Since we will pick two sequences for payment, these two initial point balances of 5,000 points (10,000 points total) comprise your \$5.00 payment for your participation in today's session. If only one sequence is played in today's session then we will add another 5000 points to your cumulative point total for that one sequence. Note that your initial or cumulative point total in each sequence will be reduced if you earn negative points in any round, so you will want to carefully review Tables A and B.

### 5. Questions

Now is the time for questions. If you have a question about any aspect of these instructions, please raise your hand and an experimenter will come to you and answer your question in private.

### 6. Quiz

Before the start of the experiment we ask you to answer the following quiz questions in the spaces provided. The numbers in these quiz questions are merely illustrative; the actual numbers in the session may be quite different. In answering these questions, please feel free to consult the Instructions and Tables A and B. After all participants have completed this quiz we will come around to check your answers.

1. Suppose Player A observes that  $W_0 = 130$  and  $af = 60$  so that the new level of water in Container 1 is 190. Player A then chooses  $M = 70$ . Suppose it turns out that  $V = 25$ . What is the final amount of water in Container 2 in this case? \_\_\_\_\_ What is the final amount of water in Container 1? \_\_\_\_\_ What is Player A's payoff in points for the round? \_\_\_\_\_ If a Player B forecast  $f = 75$ , what would be that individual Player B's payoff for the round? \_\_\_\_\_
2. Same situation as in question 1, except that Player A chooses  $M = 40$  instead of  $M = 70$ . What is the final amount of water in Container 2 in this case? \_\_\_\_\_ What is the final amount of water

- in Container 1? \_\_\_\_\_ What is Player A's payoff in points for the round? \_\_\_\_\_ If a Player B forecast  $f = 75$ , what would be that individual Player B's payoff for the round? \_\_\_\_\_
3. Suppose Player A observes that  $W_0 = 150$  and  $af = 30$  so the new level of water in Container 1 is 180. Player A then chooses  $M = 30$ . Suppose it turns out that  $V = 15$ . What is the final amount of water in Container 2 in this case? \_\_\_\_\_ What is the final amount of water in Container 1? \_\_\_\_\_ What is Player A's payoff in points for the round? \_\_\_\_\_ If a Player B forecast  $f = 35$ , what would be that individual Player B's payoff for the round? \_\_\_\_\_
  4. Same situation as in question 3, except that Player A chooses  $M = 10$  instead of  $M = 30$ . What is the final amount of water in Container 2 in this case? \_\_\_\_\_ What is the final amount of water in Container 1? \_\_\_\_\_ What is Player A's payoff in points for the round? \_\_\_\_\_ If a Player B forecast  $f = 35$ , what would be that individual Player B's payoff for the round? \_\_\_\_\_
  5. Suppose it is round 2 of a sequence. What is the chance that the sequence will continue with round 3? \_\_\_\_\_. Would your answer change if we replaced round 2 with round 12 and round 3 with round 13? Circle one: yes / no.
  6. True or false? You will remain in the same role as a Player A or Player B in all rounds of all sequences. Circle one: True / False.
  7. True or false? Player A can perfectly determine the final amount of water in Container 2. Circle one: True / False
  8. True or false? Both Player types A and B learn the final amounts of water in Containers 1 and 2. Circle one: True / False
  9. True or false? You will be paid based on the points you earned in a maximum of two sequences. Circle one: True / False.