

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, Repeated Games, Central Banking, Commitment, Discretion, Cheap Talk, Transparency, Experimental Economics.

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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. 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 this repeated policy game due to Barro and Gordon 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 that flexible, discretionary regime with a commitment regime where central bankers have the ability to pre-commit to a course for monetary policy in advance of the formation of private sector expectations, but no flexibility for stabilizing the economy.¹ 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. Given that finding, our second goal is to evaluate various mechanisms that have been suggested to be useful for overcoming the temptation to succumb to high inflation time-consistent policy making in the repeated game discretionary environment.

¹ A key 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.

In particular, we explore the role of cheap talk, policy transparency, both cheap talk and policy transparency, and finally economic transparency in overcoming the inflationary bias under discretionary policy. Many of these mechanisms have been studied in the context of Barro-Gordon type monetary policy game set-ups (see, Geraats (2002, 2014) for surveys) and thus the environment we study is appropriate for an analysis of the effectiveness of such 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 such a mechanism appear to decline with experience. In the end, we conclude that none of the various mechanisms we examine comes close to achieving the welfare levels of the commitment regime. These findings suggest that there are real welfare-reducing consequences to discretionary monetary policy.

We adopt an experimental approach for several reasons. First and most importantly, the laboratory provides us with the control necessary to properly identify whether various monetary policy regimes, e.g., commitment versus various discretionary regimes matter, for monetary policy choices, private sector expectations and welfare. The control of the laboratory enables us to choose the timing of moves and the information available so as to closely match the theory being tested in a manner that is not possible using non-experimental field data. Second, the indefinitely repeated environments we study may admit multiple equilibria so that equilibrium selection becomes an issue. As Lucas (1986, p. 237) has argued, in settings with multiple equilibria, “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.” Finally, it is of interest to assess whether the theoretical predictions of the model are robust to agents who may depart in certain respects from the rational choice ideal. 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. In particular, there is evidence that student subjects’ behavior is often not distinct from that of “professional” subjects (see, e.g. Frechette (2015)). Additionally, the literature on monetary policy emphasizes that central

bankers respond to monetary incentives (Walsh 1995), and our human subject central bankers are also incentivized to achieve good monetary policy outcomes in line with this view. Finally, while our precise 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 more 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

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 an indefinitely repeated game that continues from one round to the next with probability $5/6$. 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 pre-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.² 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 that is similar to our own. In their study subjects are divided up between policymakers and private

² 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.

sector forecasters with one policymaker and 3-5 private sector forecasters in each indefinitely lived match. 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 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 nonbeliever, humans-only, treatment.

Our experiment complements and builds upon these earlier experimental studies but differs from them in several respects. First, the Barro-Gordon (1983ab) 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 monetary policy studied by Arifovic and Sargent (2003) and Arifovic (2014). For example, in the model we study, the central banker always learns inflation forecasts *in advance* of setting policy whereas in the Arifovic-Sargent study private forecasts are only known to policymakers ex-post. 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-game 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.

Our paper is also related to experimental work involving the Stackelberg leadership model as our game always involves sequential moves though our treatments vary whether the first mover is the central bank or the private sector. Experimental research suggests that a sequential move, Stackelberg leadership structure yields higher welfare than does the comparable, simultaneous move (Cournot) model –see, e.g., Offerman et al. (2001). However, that study and other sequential move experimental games are not typically studied in indefinite-horizon environments as in this paper.

Cheap talk has also 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, once again, 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 do very much to help subjects achieve the most efficient equilibrium possible as subjects use communication for both benevolent and deceptive purposes.

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, y , is determined according to a Lucas-style aggregate supply function

$$y = y_n - c(\pi - \pi^e) + u,$$

where y_n denotes the non-accelerating inflation rate of unemployment (NAIRU), π denotes the time t inflation rate, π^e denotes private sector expectations of the inflation rate at time t , c is a constant and u 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

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

where EL denotes the expected loss, π^* is the central bank's desired inflation rate and $y^* < y_n$ 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, π^e . The central bank is informed of these expectations and takes them as given when minimizing L subject to the expressions for y and π . The central bank's reaction function, given the private sector's expectations for inflation, π^e , is given by:

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

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 $\pi^e = E(\pi) = E(m) = \frac{b\pi^* + c(y_n - y^*) + c^2\pi^e}{b + c^2}$, or that $\pi^e = \pi^* + \frac{c}{b}(y_n - y^*)$, which implies that the money supply in Nash equilibrium is:

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

Thus the policy choice in the Nash equilibrium (NE) of the one-shot discretionary environment involves an inflation rate, π^{NE} , that is greater than the desired level, π^* , by the amount $\frac{c}{b}(y_n - y^*)$, which reflects the

well-known inflationary bias of discretionary policy. The third and final term, $\frac{c}{b+c^2}u$, reflects the central bank's incentive for stabilizing employment by adjusting the money supply to supply shocks, u .

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

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

We refer to this regime as one of “economic transparency” (ET) and 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 central bank moves first and pre-commits to set m in advance of private sector expectation formation but may be able to condition this decision on realizations of the shock, u_t . The central bank 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:

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

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 optimal inflation rate irrespective of the supply shock. Comparing this case to the Nash equilibrium under economic transparency, both problems of time inconstancy are solved by the CB's ability to commit: inflation is both stable and at the optimal 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.³ 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

Our experiment implements a dynamic repeated-game version of the model described in the previous section. 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 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 outcome, where $\pi_t^e = \pi^*$, can be sustained as an equilibrium of the infinitely repeated game.

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

³ 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.

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

subject to the given processes for π_t and y_t . Depending on the information available to the private sector, e.g., whether they learn ex-post about the policy rule $m(u)$, and provided that the discount factor δ is sufficiently large, the Folk theorem for infinitely repeated games applies so that the set of equilibria ranges from the one-period discretionary Nash equilibrium where $m_t = \pi^{NE} + \frac{c}{b+c^2}u_t$ and private sector expectations satisfy $\pi_t^e = \pi^{NE}$ to the efficient “Ramsey” solution where the central bank sets $m_t = \pi^* + \frac{c}{b+c^2}u_t$, avoiding the inflation bias, because $\pi_t^e = \pi^*$, but at the same time having the flexibility to stabilize employment. 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 for the Ramsey solution being equilibrium of the repeated game. We assume throughout that the private sector will learn inflation π_t and unemployment y_t at the end of the period. Knowing the Phillips curve, it can thereby deduce the supply shock u_t . 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 (as assumed by Barro and Gordon (1983b)), expectations in period $t+1$ can be conditioned on the actual relationship between m_t and u_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, as long as the central bank follows the Ramsey rule. If, however, the central bank deviates from this policy in any period τ , 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 u_0 , which yields $m_0 = \pi^* + \frac{c}{b+c^2}(y_n - y^* + u_0)$ and gives rise to a welfare loss of

$$\begin{aligned}
L_0^D(u_0) &= E \left[b \left(\frac{c}{b+c^2}(y_n - y^* + u_0) + v_0 \right)^2 + \left(y_n - c \left(\frac{c}{b+c^2}(y_n - y^* + u_0) + v_0 \right) + u_0 - y^* \right)^2 \middle| u_0 \right] \\
&= b \left(\frac{c}{b+c^2}(y_n - y^* + u_0) \right)^2 + b\sigma_v^2 + \left(\frac{b}{b+c^2}(y_n - y^* + u_0) \right)^2 + c^2\sigma_v^2 \text{ [skip this line in publication]} \\
&= \frac{b}{b+c^2}(y_n - y^* + u_0)^2 + (b+c^2)\sigma_v^2.
\end{aligned}$$

The expected welfare loss associated with a deviation from Ramsey is then given by $L_0^D(u_0) + \sum_{t=1}^{\infty} \delta^t E(L^{NE})$, where $E(L^{NE})$ is the prior expected welfare loss in the one-period Nash-equilibrium:

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

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

$$\begin{aligned}
L^R(u_0) &= E \left[b \left(\frac{c}{b+c^2}u_0 + v_0 \right)^2 + \left(y_n - c \left(\frac{c}{b+c^2}u_0 + v_0 \right) + u_0 - y^* \right)^2 \middle| u_0 \right] \\
&= b \left(\frac{c}{b+c^2}u_0 \right)^2 + b\sigma_v^2 + \left(y_n - y^* + \frac{b}{b+c^2}u_0 \right)^2 + c^2\sigma_v^2 \text{ [skip this line in publication]} \\
&= (y_n - y^*)^2 + \frac{b}{b+c^2}(u_0^2 + 2u_0(y_n - y^*)) + (b+c^2)\sigma_v^2.
\end{aligned}$$

The period-0 expectation of future losses under Ramsey is

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

Thus, the central bank has *no* incentive to deviate, if and only if $L_0^D(u_0) + \sum_{t=1}^{\infty} \delta^t E(L^{NE}) \geq L_0^R(u_0) + \sum_{t=1}^{\infty} \delta^t E(L^R)$, which is equivalent to

$$\begin{aligned}
\frac{b}{b+c^2} (y_n - y^* + u_0)^2 - (y_n - y^*)^2 - \frac{b}{b+c^2} (u_0^2 + 2u_0(y_n - y^*)) &\geq \sum_{t=1}^{\infty} \delta^t \left[-\frac{c^2}{b} (y_n - y^*)^2 \right] \\
\Leftrightarrow \frac{-c^2}{b+c^2} (y_n - y^*)^2 \geq \frac{-\delta}{1-\delta} \cdot \frac{c^2}{b} (y_n - y^*)^2 &\Leftrightarrow (1-\delta)b \leq \delta(b+c^2) \Leftrightarrow \delta \geq \frac{b}{2b+c^2}. \tag{1}
\end{aligned}$$

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

If policy is intransparent, 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.⁴

Suppose v has a uniform distribution in $[-\mu, \mu]$ and consider the following strategy of forecasters: Expectations start with Ramsey and switch to Nash forever from period $t+1$ onwards, if $\pi_t > \pi^* + \mu$. 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

⁴ 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.

unemployment from high levels at the risk of a moderate probability of being punished in the future. If μ is large, the probability of detection is small, provided that m exceeds π^* 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.

If the money supply rises to $m \in (\pi^*, \pi^* + 2\mu)$, the probability of being detected is $prob(\pi > \pi^* + \mu | m) = \frac{m - \pi^*}{2\mu}$.⁵ The associated expected welfare loss in the current period, say $\tau = 0$, is

$$\begin{aligned} E(L|u_0, m) &= E[b(m + v - \pi^*)^2 + (y_n - c(m + v - \pi^*) + u_0 - y^*)^2 | u_0] \\ &= b(m - \pi^*)^2 + b\sigma_v^2 + c^2(m - \pi^*)^2 - 2c(m - \pi^*)(y_n - y^* + u_0) + (y_n - y^* + u_0)^2 + c^2\sigma_v^2 \text{ [skip]} \\ &= (b + c^2)(m - \pi^*)^2 - 2c(m - \pi^*)(y_n - y^* + u_0) + (y_n - y^* + u_0)^2 + (b + c^2)\sigma_v^2. \end{aligned}$$

Thus, the marginal expected gain from increasing m is $\frac{-\partial E(L|u_0, m)}{\partial m} = 2c(y_n - y^* + u_0) -$

$2(b + c^2)(m - \pi^*)$. The marginal expected loss is $\frac{1}{2\mu} \sum_{t=1}^{\infty} \delta^t (E(L^{NE} - L^R)) = \frac{\delta}{1-\delta} \cdot \frac{c^2}{2\mu b} (y_n - y^*)^2$. A

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

$$2c(y_n - y^* - u_0) \leq \frac{\delta}{1-\delta} \cdot \frac{c^2}{2\mu b} (y_n - y^*)^2 \Leftrightarrow 4\mu b(y_n - y^* - u_0) \leq \frac{\delta}{1-\delta} \cdot c(y_n - y^*)^2.$$

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

⁵ 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.

$$\begin{aligned}
& 4\mu b(y_n - y^* + u_{max}) \leq \frac{\delta}{1-\delta} \cdot c(y_n - y^*)^2 \\
\Leftrightarrow & (1 - \delta)4\mu b(y_n - y^* + u_{max}) \leq \delta c(y_n - y^*)^2 \quad [\text{skip this line in publication}] \\
\Leftrightarrow & 4\mu b(y_n - y^* + u_{max}) \leq \delta [c(y_n - y^*)^2 + 4\mu b(y_n - y^* - u_{min})] \quad [\text{skip this line in publication}] \\
\Leftrightarrow & \delta \geq \frac{4\mu b(y_n - y^* + u_{max})}{c(y_n - y^*)^2 + 4\mu b(y_n - y^* + u_{max})}, \quad (2)
\end{aligned}$$

where u_{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.⁶ Subjects remained in the *same* 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. For instance we did not want players to imagine they were central bankers choosing an inflation rate because they might have used their own experience from the real economy to coordinate on a particular rate, and we wanted the incentive structure of the model to determine their decisions instead.

We told subjects to imagine that the two variables, y_t and π_t , stand for two “containers” holding varying amounts of water⁷. 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, y_n , in the model while the supply shock $u_t = w_t - E[w_t]$. Thus, in our parameterization one can think of the adverse supply shock, u_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., $w_t = y_n + u_t$. 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.

⁶ 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.

⁷ 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).

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, $\pi_{i,t}^e$, as to how many gallons (liters) of 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, π^* , 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 π_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 π_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 $y_t = y_n + \pi_t^e - \pi_t + u_t$ while the final amount of water in Container 2 corresponds to $\pi_t = m_t + v_t$.

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: $y^* = 120$ 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 π_t , the amount of water in Container 2 correctly.⁸ 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

⁸ 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 agent 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 the Appendix. 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 y_t and π_t and their point earnings for the round as determined by the expressions given above. In addition, type B players learn the realization of $w_t = y_n + u_t$. As they were told at the outset that the mean value for $w_t = 140 = y_n$, in effect they learn the realization of the supply shock u_t 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 that a six-sided die would be rolled to determine whether the sequence continued with another round; they were further instructed that if a six was rolled, 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 indefinite sequence might begin.

Subjects were informed that at the end of the session (which could last up to three hours), two sequences would be randomly chosen from among all those 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 randomly drawn at the end, the endowment served as subjects' show-up payment.

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 pre-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 u_t when forming their expectations, $\pi_{i,t}^e$. The policy maker observes u_t and π_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, y_t and π_t and are informed of the values for u_t and π_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, u_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 pre-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 u_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, thus making it transparent as to whether inflation was high (low) due to the transmission shock or due to the policymaker’s choice. 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 u_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 unemployment and inflation target y^* and π^* 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 $y_n = 140$ and $y^* = 120$, the difference between efficient and natural unemployment is 20, so we may think of units of y 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 π must correspond to .2 percent inflation. Since the standard deviation of supply shocks u is 11.55 and a unit of y 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 π 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 $\frac{c}{b}(y_n - y^*) = 40$ and, since units of π 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 ($u = 10$). In our economy, the optimal response would be an increase of π 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 $u_{max} = 20$, the sufficient condition for the Ramsey solution to be an equilibrium in the regimes without policy transparency is $\delta \geq \frac{4\mu b(y_n - y^* + u_{max})}{c(y_n - y^*)^2 + 4\mu b(y_n - y^* + u_{max})} = \frac{40*40}{(20)^2 + 40*40} = 0.8$. 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 $\text{Std}[y] = \sqrt{\text{Var}[v] + \text{Var}[u]} = 16.33$. Expectations should be rational and equal to π^* , 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

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

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 $\partial m / \partial u = 2/3$. 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 $\pi^* - E(v) + \frac{2}{3}u_{min} = 6.67$ under Ramsey to $\pi^* + 40 + E(v) + \frac{2}{3}u_{max} = 73.33$. Our subject central bankers can choose values of $m \in [0, 80]$, which contains all of these values in the interior, allowing us to test the point predictions associated with the most extreme equilibria.

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, u_t .	0	2/3	2/3	2/3	2/3	2/3 2 *
Response of m_t to exp inflation, π_t^e .	n.a.	2/3	2/3	2/3	2/3	2/3
Response of π_t^e to supply shock, u_t	0	n.a.	0	n.a.	0	2
St.Dev. of π_t	11.55	13.88	13.88	13.88	13.88	25.82
St. Dev. of y_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 $\text{Std}[\pi] = \sqrt{\text{Var}[v] + \frac{4}{9}\text{Var}[u]} = 13.88$, while it reduces the standard deviation of unemployment to $\text{Std}[y] = \sqrt{\text{Var}[v] + \frac{1}{9}\text{Var}[u]} = 12.17$. 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:

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

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

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

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 $\text{Std}[\pi] = \sqrt{\text{Var}[v] + 4\text{Var}[u]} = 25.82$, while $\text{Std}[y] = 16.33$ 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

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

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

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 CB 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 reflects 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

As noted in section 4.1 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 (2 per session) constitutes an independent observation.

Sessions were conducted at the Technical University of Berlin and the University of Pittsburgh. Specifically, two sessions of all 6 treatments were conducted in Berlin and two sessions of all 6 treatments were conducted in Pittsburgh. Therefore, we have 8 matching groups of 10 subjects (our observational unit) for each of our 6 treatments (4 groups from Berlin and 4 groups from Pittsburgh), for a total of $8 \times 10 \times 6 = 480$ subjects. We did not find substantial differences in behavior between the 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 read instructions aloud (see the Appendix for the sample instructions from the baseline discretionary treatment) and had to answer quiz questions before playing a number of supergames that constituted our experiment. Each session lasted 2-3 hours (subjects were always invited for 3 hours) and involved one or more open-ended sequences (supergames). Subjects were paid their earnings from 1 or a maximum of 2 supergames (the latter case applied if 2 or more supergames were played). They did not know in advance, which supergames were chosen for payoffs. Total payoffs ranged from USD \$13.30 to \$56.46.

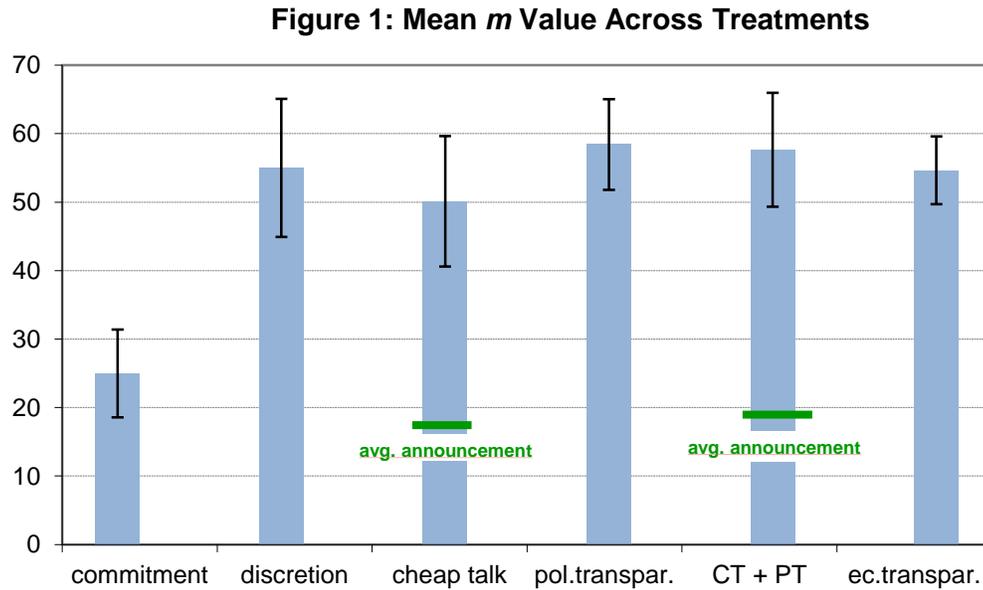
5. Experimental Results

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

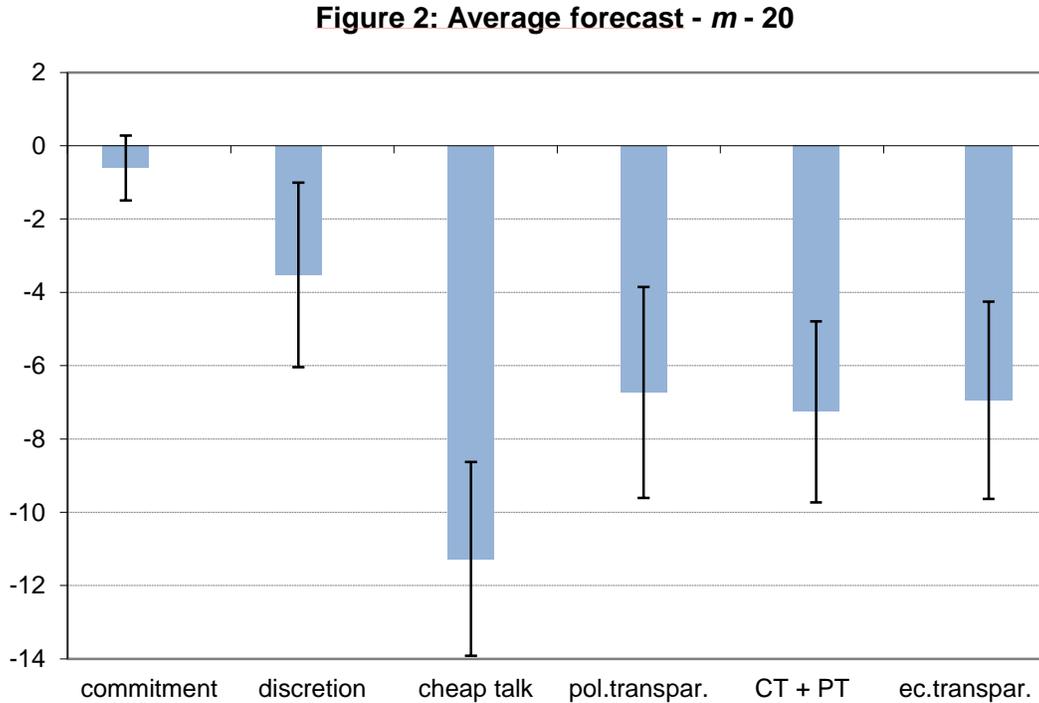
mean announced value of m in the two treatments involving pre-game communication. The Figure shows clearly that the mean choice of m in the commitment treatment is indistinguishable from the Ramsey solution $m=20$, whereas the mean value of m in the other 5 treatments is significantly greater than 20.



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

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.



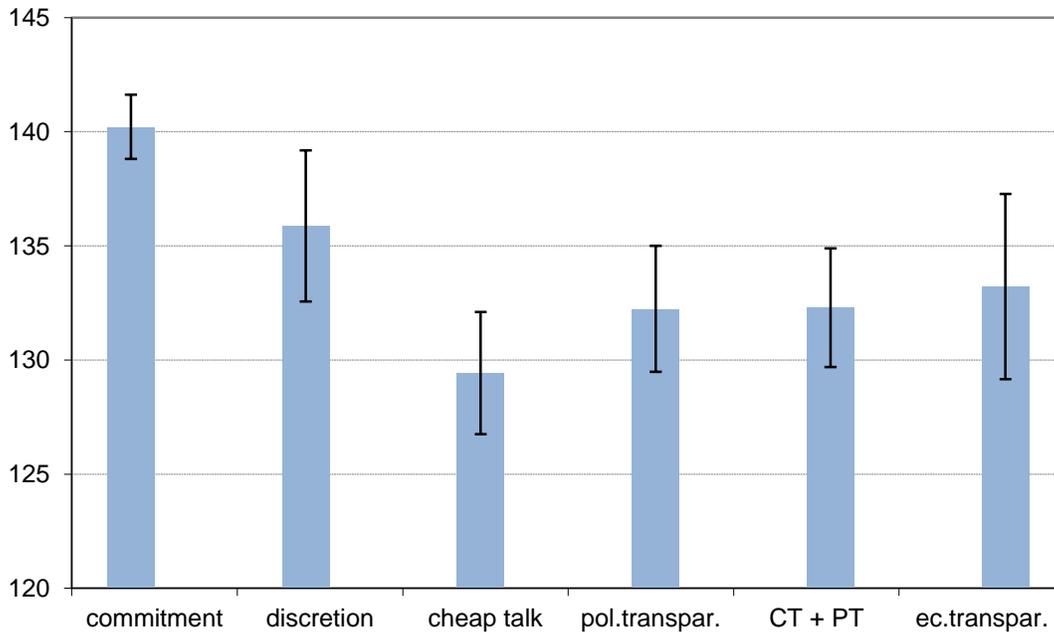
Finding 2: *Inconsistent with Hypothesis 3, private sector expectations are biased in the five discretionary treatments, though not in the commitment treatment. In the discretionary treatments, private sector agents systematically under-predict inflation.*

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 NAIU. 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 (NAIU) 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.

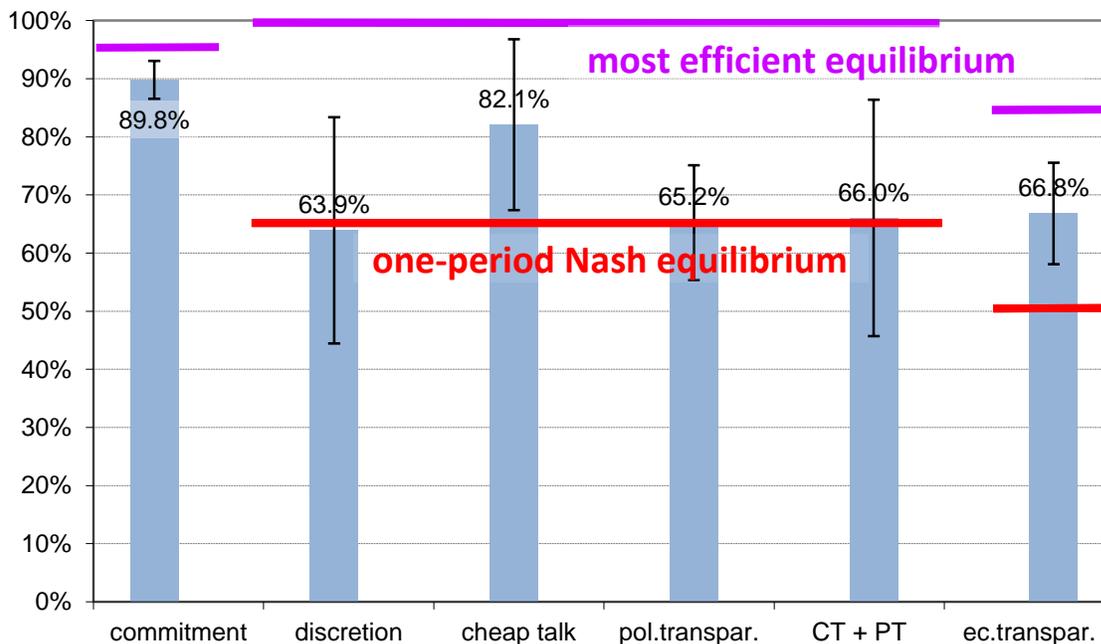
Figure 3: Average unemployment (final Container 1 amount)



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 for central bank behavior was

$$m_t^i = \alpha + \beta_1 u_t + \beta_2 avgf_t,$$

where m_t^i is the CB player i 's money supply choice at time t , and u_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 . We impose the additional restriction that $\beta_2 = 0$ for the commitment treatment (where the central bank had to decide on m before knowing the private sector's forecast). The regression results are displayed in Table 2.

Table 2: Central Bank Behavior

Treat. Parameter	Commitment	Discretion	Cheap Talk	Policy Transparency	CT + PT	Economic Transparency
α	-35.91*** (5.68)	-2.75 (7.62)	-49.29*** (5.79)	-23.69** (9.43)	-30.43*** (8.14)	-32.21*** (7.20)
β_1	0.43*** (0.04)	0.35*** (0.04)	0.50*** (0.04)	0.48*** (0.05)	0.48*** (0.05)	0.40*** (0.06)
β_2	-	0.14** (0.06)	0.49*** (0.05)	0.21** (0.09)	0.30*** (0.07)	0.46*** (0.08)
R ²	0.07	0.25	0.57	0.22	0.38	0.38

The estimated coefficient, β_1 , is significantly positive in all treatments ($p < 1\%$) indicating that central bankers are responding to supply shocks in all six treatments. The significantly positive estimate for β_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 β_1 in the five discretionary treatments are not significantly different from the estimated β_1 in 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 β_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 β_2 coefficients that are significantly positive, but also significantly less than the $2/3$ prediction of the one-shot Nash equilibrium ($p < 5\%$) in all of the discretionary treatments except economic transparency where we cannot reject the null that $\beta_2 = 2/3$. Hypothesis 2b, that $\beta_1 = \beta_2$ in each of the five discretionary regimes, is rejected for the discretionary, policy transparency (PT) and cheap talk plus policy transparency (CT+PT) treatments according to an F-test ($p < 5\%$). In the other two discretionary treatments, cheap talk and economic transparency, CB players *are* attaching approximately equal weight to supply shocks and inflation expectations, consistent with Hypothesis 2B. We can also make comparisons *across* discretionary treatments as to whether the coefficient

estimates for either β_1 or β_2 differ pairwise between discretionary treatments. Using a Z-test, we find that β_1 is significantly greater in the cheap talk, PT and CT+PT treatments as compared with the discretion treatment ($p < 5\%$). Additionally, β_2 is significantly greater in the cheap talk and ET treatments as compared with the discretionary and PT treatments and β_2 is significantly greater in cheap talk treatment as compared with the CT+PT treatment ($p < 5\%$). Thus, it appears that the addition of cheap talk in particular, helps to raise the responsiveness of the central bank to supply shocks and average inflation expectations; indeed, coefficient estimates for β_1 and β_2 are highest in the cheap talk treatment. Summarizing we have:

Finding 4: *Central bank responses to supply shocks are positive in all treatments, contrary to the equilibrium prediction for the commitment regime. The estimated weights attached to supply shocks and inflation expectations are highest for the cheap talk treatment but are still lower than equilibrium predictions for all discretionary treatments and the estimates are often significantly unequal, which is inconsistent with Hypotheses 2B.*

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, u_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

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

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
α	18.81*** (0.58)	13.97*** (1.79)	36.52*** (1.97)	29.28*** (4.26)	29.45*** (2.60)	46.29*** (2.90)	43.58*** (4.78)	-20.46*** (4.37)
δ_1	0.96*** (0.01)	-	-	-	-	-	-	-
δ_2	-	-	0.42*** (0.02)	-	-	0.18*** (0.02)	-	-
δ_3	-	-	-	0.08*** (0.03)	-	-	0.05* (0.03)	0.52*** (0.02)
β_1	0.01 (0.03)	0.13*** (0.03)	0.04 (0.03)	0.04 (0.03)	0.18*** (0.03)	0.03 (0.03)	0.03 (0.03)	-0.05 (0.03)
β_2	0.05*** (0.01)	0.29*** (0.01)	0.13*** (0.02)	0.11*** (0.02)	0.14*** (0.01)	0.10*** (0.02)	0.08*** (0.02)	0.12*** (0.02)
β_3	-0.03 (0.03)	0.39*** (0.03)	0.09** (0.04)	0.15*** (0.05)	0.27*** (0.04)	0.17*** (0.05)	0.18*** (0.05)	0.17*** (0.05)
R ²	0.80	0.74	0.38	0.46	0.58	0.41	0.52	0.25

Note: *** significant at 1%, ** significant at 5%, * significant at 10%, numbers in parantheses are estimated standard deviations.

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, δ_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 δ_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, u_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 δ_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 monetary policy choice. 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 further reveals that in all treatments, subjects' forecasts respond to lagged inflation as evidenced by the significantly positive coefficient estimates for β_2 , which suggests evidence of adaptive learning. Numerically, this effect is smallest for commitment and highest for the pure discretionary treatment. Further, as β_3 is significantly positive in all discretionary treatments, individual forecasts converge over time.⁹

⁹ 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.

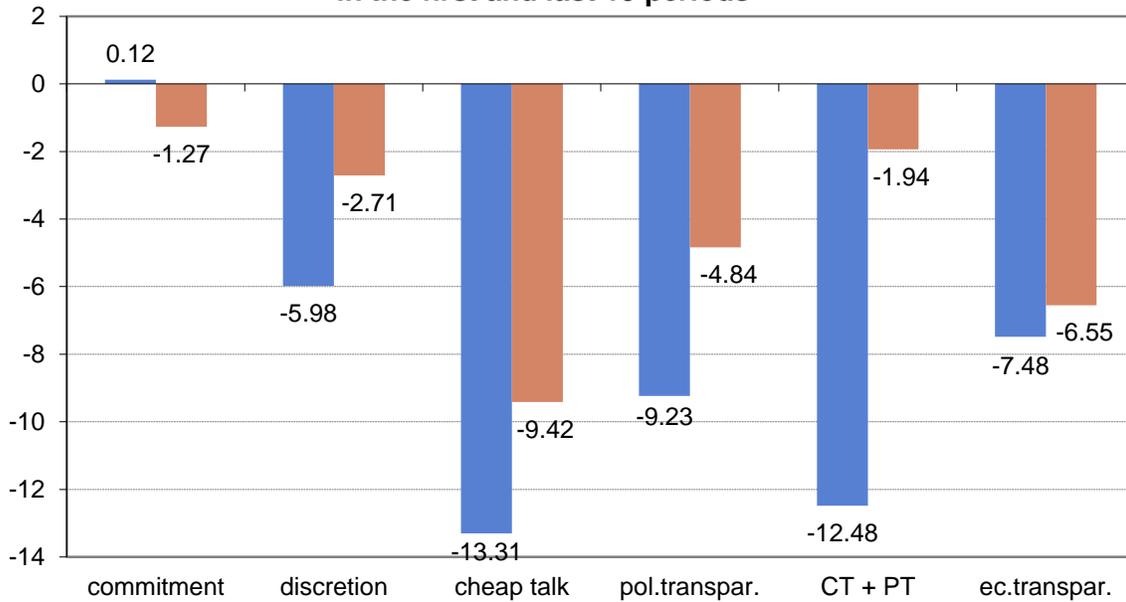
If forecasters are learning, it is puzzling that their expectations are systematically biased towards too low an inflation rate, which runs counter to Hypotheses 3 and 4. Nevertheless, it may be that this bias becomes smaller over time. In order to address that question, we analyze the data on expectation bias separately for the first and last 15 periods of each treatment¹⁰ 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). 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 ($p < 1\%$).¹¹ 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).*

¹⁰ 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.

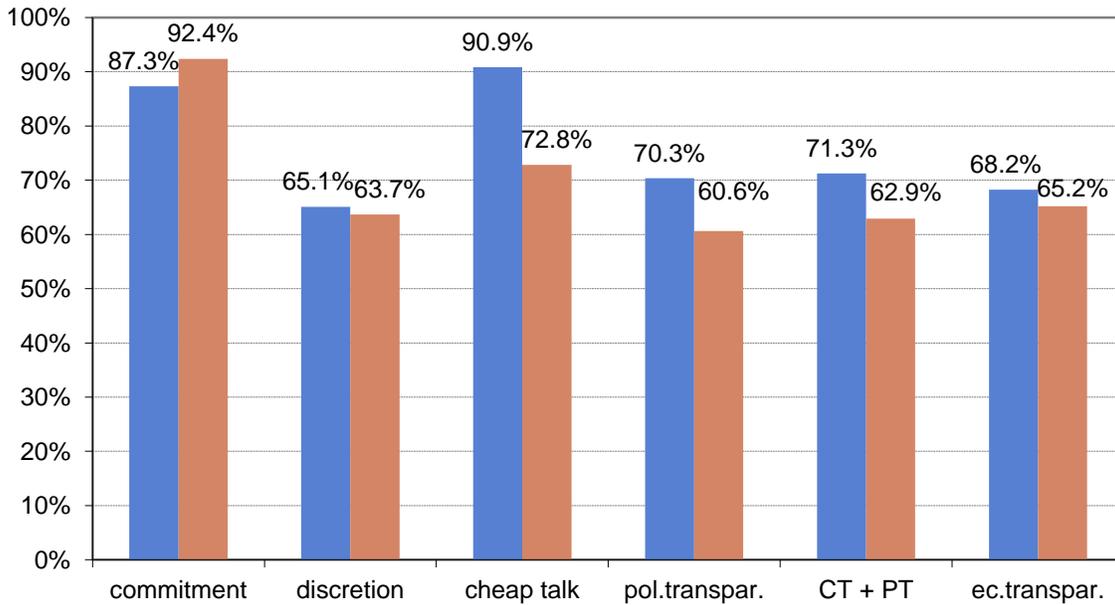
¹¹ We observe a significant reduction in money supply under commitment ($p = 5.5\%$). In other treatments, there are no significant differences between money supply in the first and last periods ($p > 19\%$).

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
std(y_t)	16.56	19.48	17.73	18.66	19.03	20.55
equilibrium	16.33	12.17	12.17	12.17	12.17	16.33

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,¹² 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 unemployment with more fluctuations as under constant expectations and constant money supply. With specific regard to Hypothesis 6, we have the following:

¹² 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.

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 δ_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 $\text{std}(y)$ 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.¹³

Table 5: Standard Deviation of Inflation

	Commitment	Discretion	Cheap Talk	Policy Transparency	CT + PT	Economic Transparency
St.Dev. of π_t	18.86	19.94	19.60	18.44	17.93	20.28
Equilibrium	11.55	13.88	13.88	13.88	13.88	25.82

¹³ Ahrens et al. (2016) are currently working on a comparable experiment in which they focus on the effects of forward guidance.

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 under 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 economic transparency, 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
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:

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

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)
α	-26.43*** (8.38)	-28.72*** (8.79)	-23.54*** (8.57)	2.45 (10.64)	18.75 (12.16)	12.46 (12.01)
δ_1	0.28*** (0.06)	0.28*** (0.06)	0.28*** (0.06)	0.19*** (0.07)	0.17** (0.08)	0.20*** (0.08)
β_1	0.02 (0.06)	-	-	0.04 (0.04)	-	-
β_2	-	0.05 (0.06)	0.04 (0.06)	-	-0.20*** (0.06)	-0.20*** (0.06)
β_3	0.05 (0.06)	0.06 (0.06)	-	-0.19 (0.06)	-0.26*** (0.07)	-
β_4	-	-	-0.02 (0.04)	-	-	-0.15*** (0.05)
R ²	0.08	0.02	0.01	0.04	0.08	0.11

Note: *** significant at 1%, ** significant at 5%, numbers in parantheses are estimated standard deviations.

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 δ_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 β_1 . Finally, the significantly negative coefficient estimates for β_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 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 among 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” as well 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 subjects 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: Instructions Used in the Baseline Discretionary Treatment (Other Instructions are Similar)

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.

We will first go over these instructions. When we are done, each of you will have to answer a few brief questions to ensure that all participants understand these instructions. You will also have time to ask clarifying questions. Then, you will begin making your decisions using the computer workstations.

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 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 4 participants will remain in your role of Player A or 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 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, Player A learns both W_0 and af and thereby the total amount of water in Container 1. Then, Player A can move up to 80 gallons of water from Container 1 to Container 2. Denote the amount moved by M .

In addition, there is an uncontrolled flow of water V from Container 1 to Container 2. 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 the value of W_0 randomly from a **uniform distribution over the interval [120, 160]**, which 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 B**'s in each group move first. Each must submit a forecast, f , of the 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 units of water inclusive in Container 2. Player Bs should type their forecast in the input box on the first decision screen when prompted. Click the OK 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*. We denote this average forecast by af . Then, af units of water are added to Container 1. So, 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 know precisely the value of W_0 nor do they know af ; they do know that W_0 is a uniform draw from [120, 160] and 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 input box on the first decision screen when prompted. Click the OK button when satisfied with your choice.

In addition, there is an uncontrolled flow of water from Container 1 to Container 2. This flow 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.

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 the round according to the formula:

$$\text{Player A Points} = 4000 - 2(\text{Final Container 1 amount} - 120)^2 - (\text{Final Container 2 amount} - 40)^2$$

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 if 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 of 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 the round is given by the formula:

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

Note 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 payoff in points is given in Table B (attached) as a function of the forecast error, Final Container 2 amount $- f$. Notice that Player B's maximize their payoffs when the forecast error is 0, that is when f =Final Container 2 amount.

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 . They will then be told the value of the random variable V , and the final amounts of water in Containers 1 and 2. Finally, Player A's will be told their 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 choice of f . They will then be told the final amounts of water in Containers 1 and 2 and the value of the random variable W_0 . Finally, they will be told their 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 sheets 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. If a new round is played, the procedure will be the same as described 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.

Depending on the time available, a new sequence may then begin. At the start of this 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 if you had to return for a continuation of a sequence, you would also be paid based on your cumulative point total for that final sequence, once it had finally ended.

4. Earnings

If 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 the session will equal your point total from that sequence. If two or more sequences have been played, then your point total for the session will be the sum of your cumulative point totals from two sequences. One of these two sequences will be the one in which you earned the *highest* cumulative point total from among all sequences played in today's session. The other sequence will be one that is 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 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, then you would be paid for one randomly chosen sequence that ended in today's session (provided that event occurred) and/or for the final sequence, when that final sequence finally ended, in a later continuation session.

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 total) comprise your \$5.00 payment for participation in this 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 is reduced by negative points earned in any round.

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. Feel free to consult the instructions and tables to answer these questions. 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 $M=40$. 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? You will be paid based on the points you earned in a maximum of two sequences. Circle one: True / False.

Table B: Player B's Payoff in Points=4000-(Final Container 2 amount -f)²

Forecast, f of Container 2 Amt.		Amount in Container 2 →																								
		0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115	120
0	↓	4000	3975	3900	3775	3600	3375	3100	2775	2400	1975	1500	975	400	-225	-900	-1625	-2400	-3225	-4100	-5025	-6000	-7025	-8100	-9225	-10400
5		3975	4000	3975	3900	3775	3600	3375	3100	2775	2400	1975	1500	975	400	-225	-900	-1625	-2400	-3225	-4100	-5025	-6000	-7025	-8100	-9225
10		3900	3975	4000	3975	3900	3775	3600	3375	3100	2775	2400	1975	1500	975	400	-225	-900	-1625	-2400	-3225	-4100	-5025	-6000	-7025	-8100
15		3775	3900	3975	4000	3975	3900	3775	3600	3375	3100	2775	2400	1975	1500	975	400	-225	-900	-1625	-2400	-3225	-4100	-5025	-6000	-7025
20		3600	3775	3900	3975	4000	3975	3900	3775	3600	3375	3100	2775	2400	1975	1500	975	400	-225	-900	-1625	-2400	-3225	-4100	-5025	-6000
25		3375	3600	3775	3900	3975	4000	3975	3900	3775	3600	3375	3100	2775	2400	1975	1500	975	400	-225	-900	-1625	-2400	-3225	-4100	-5025
30		3100	3375	3600	3775	3900	3975	4000	3975	3900	3775	3600	3375	3100	2775	2400	1975	1500	975	400	-225	-900	-1625	-2400	-3225	-4100
35		2775	3100	3375	3600	3775	3900	3975	4000	3975	3900	3775	3600	3375	3100	2775	2400	1975	1500	975	400	-225	-900	-1625	-2400	-3225
40		2400	2775	3100	3375	3600	3775	3900	3975	4000	3975	3900	3775	3600	3375	3100	2775	2400	1975	1500	975	400	-225	-900	-1625	-2400
45		1975	2400	2775	3100	3375	3600	3775	3900	3975	4000	3975	3900	3775	3600	3375	3100	2775	2400	1975	1500	975	400	-225	-900	-1625
50		1500	1975	2400	2775	3100	3375	3600	3775	3900	3975	4000	3975	3900	3775	3600	3375	3100	2775	2400	1975	1500	975	400	-225	-900
55		975	1500	1975	2400	2775	3100	3375	3600	3775	3900	3975	4000	3975	3900	3775	3600	3375	3100	2775	2400	1975	1500	975	400	-225
60		400	975	1500	1975	2400	2775	3100	3375	3600	3775	3900	3975	4000	3975	3900	3775	3600	3375	3100	2775	2400	1975	1500	975	400
65		-225	400	975	1500	1975	2400	2775	3100	3375	3600	3775	3900	3975	4000	3975	3900	3775	3600	3375	3100	2775	2400	1975	1500	975
70		-900	-225	400	975	1500	1975	2400	2775	3100	3375	3600	3775	3900	3975	4000	3975	3900	3775	3600	3375	3100	2775	2400	1975	1500
75		-1625	-900	-225	400	975	1500	1975	2400	2775	3100	3375	3600	3775	3900	3975	4000	3975	3900	3775	3600	3375	3100	2775	2400	1975
80		-2400	-1625	-900	-225	400	975	1500	1975	2400	2775	3100	3375	3600	3775	3900	3975	4000	3975	3900	3775	3600	3375	3100	2775	2400
85		-3225	-2400	-1625	-900	-225	400	975	1500	1975	2400	2775	3100	3375	3600	3775	3900	3975	4000	3975	3900	3775	3600	3375	3100	2775
90		-4100	-3225	-2400	-1625	-900	-225	400	975	1500	1975	2400	2775	3100	3375	3600	3775	3900	3975	4000	3975	3900	3775	3600	3375	3100
95		-5025	-4100	-3225	-2400	-1625	-900	-225	400	975	1500	1975	2400	2775	3100	3375	3600	3775	3900	3975	4000	3975	3900	3775	3600	3375
100		-6000	-5025	-4100	-3225	-2400	-1625	-900	-225	400	975	1500	1975	2400	2775	3100	3375	3600	3775	3900	3975	4000	3975	3900	3775	3600
105		-7025	-6000	-5025	-4100	-3225	-2400	-1625	-900	-225	400	975	1500	1975	2400	2775	3100	3375	3600	3775	3900	3975	4000	3975	3900	3775
110		-8100	-7025	-6000	-5025	-4100	-3225	-2400	-1625	-900	-225	400	975	1500	1975	2400	2775	3100	3375	3600	3775	3900	3975	4000	3975	3900
115		-9225	-8100	-7025	-6000	-5025	-4100	-3225	-2400	-1625	-900	-225	400	975	1500	1975	2400	2775	3100	3375	3600	3775	3900	3975	4000	3975
120		-10400	-9225	-8100	-7025	-6000	-5025	-4100	-3225	-2400	-1625	-900	-225	400	975	1500	1975	2400	2775	3100	3375	3600	3775	3900	3975	4000