A Classroom Experiment in Monetary Policy

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ABSTRACT

We propose a classroom experiment implementing a simple version of a New Keynesian model suitable for courses in intermediate macroeconomics and money and banking. Students play as either the central bank or members of the private sector. The central banker sets interest rates to meet either twin objectives for inflation and the output gap or to meet only an inflation target. In both settings, private sector agents are concerned with correctly forecasting the inflation rate. We show that an experiment implementing this setup is feasible and yields results that enhance understanding of the New Keynesian model of monetary policy. We propose alternative versions where the central bank is replaced by a policy rule and we provide suggestions for discussing the experimental results with students.

Keywords: undergraduate teaching, experiment, monetary policy

JEL codes: A22, C90, E52

Discussions of monetary policy using versions of the New Keynesian model are now commonplace in undergraduate courses in intermediate macroeconomics and in money and banking.[1] Since the New Keynesian model forms the basis for much contemporary macroeconomic research and monetary policymaking, economics students should understand the fundamental mechanics of the model. In particular, students should learn that the private sector's inflation expectations directly affect the actual inflation rate and therefore the appropriate monetary policy response to exogenous macroeconomic shocks. Students should also learn that the principle job of the central bank is the management of inflationary expectations and that the central bank's job is made more difficult if the central bank is charged with stabilizing both inflation and output. Finally, students should also be exposed to the debate about rules versus discretion in monetary policy decision making.

In this paper, we describe a new classroom experiment for teaching the New Keynesian model that achieves all of the above-stated learning objectives. Students are asked to form inflation expectations, set monetary policy, and get to observe the effects of their actions on aggregate outcomes. In an alternative version of our experiment that we consider, the central bank is replaced with a policy rule for setting interest rates, enabling a comparison of outcomes in that setting with the one involving discretionary (human) central bankers. The experiment is designed for students in intermediate-level macroeconomics and money and banking courses. We provide instructions for running the experiment, a link to computer software for running the experiment, and suggestions for leading an in-class discussion of the experimental results.[2]

In our experiment, students are assigned to groups of five with each group operating as an independent economy (other configurations are possible, as discussed in the section "Classroom Experiment"). In each group, one student is assigned to play the role of the central banker and the other four students are assigned to play as members of the private sector. The experiment has ten consecutive periods that can be thought of as quarters of a year. At the beginning of each period, the private sector forms an inflation forecast. Then, after observing the private sector's inflation forecast together with the values of any aggregate exogenous shocks, each central banker chooses an interest rate to meet inflation and output targets. The students observe the equilibrium at the end of each period. Since they get immediate feedback, students can adjust their behavior as they learn how the model works.

We provide instructions and software to run the program in the classroom and we also discuss how the experiment can be implemented with paper and pencil. We report results from tests of the experiment using students from several intermediate macroeconomics courses taught at the University of California, Irvine. We tried two different central bank regimes: a dual mandate regime and a pure inflation targeting regime. In the first regime, which mirrors the legislated "dual mandate" of the U.S. Federal Reserve, central bankers were incentivized to set the interest rate to simultaneously meet inflation and output gap targets. In the alternative regime, central banks were incentivized to set the interest rate to meet only an inflation target.

We observe a wide variety of outcomes. Under both policy regimes, there were groups that converged nearly perfectly to the rational expectations equilibrium, but there were other groups that did not. In particular, some groups experienced explosive hyper-inflationary episodes providing excellent opportunities for classroom discussion. Further, we find that groups in the inflation targeting regime were more likely to converge to the rational expectations equilibrium than groups in the dual mandate regime. Evidently, the inflation targeting regime makes the model easier to understand presumably because the central bank's objective is easier to understand. This lesson underlies an important argument for inflation targeting in practice that is not easily conveyed without the experience of participating in the experiment.

Classroom experiments have been shown to enhance the undergraduate experience in economics courses (Dickie 2006, Emerson and English 2016). The experiment described in this paper adds to the few experiments that have been developed for courses in macroeconomics or monetary economics (See Denise Hazlett's website for examples of other experiments for macroeconomics.[3]). To our knowledge, there are no classroom experiments for teaching monetary policy using a simplified New Keynesian model. We suggest how the experiment can be implemented over the course of a one-hour lecture period and how the results can be analyzed and evaluated in a homework assignment. Reviews from student subjects in our classroom experiments are generally favorable and suggest that this experiment can be a good substitute for the standard lecture format approach to teaching monetary policy.

THEORY

In this section, we describe the theoretical model behind our experiment. We use a non-dynamic, reduced form New Keynesian model based on the one proposed by Bofinger, Mayer and Wollmershuser (2006). Similar versions of the model can also be found in several modern macroeconomic textbooks including Chugh (2015), Mankiw (2016), Mishkin (2016), and Jones (2017), and are sometimes referred to as the IS-Monetary Policy (IS-MP) model. Our version comprises an expectations-augmented Phillips curve and an IS equation. The central bank has full discretion to set monetary policy in each period through its choice of the interest rate. We solve for optimal monetary policy in the model and we derive the rational expectations equilibrium to use as a benchmark for evaluating equilibria realized during the experiment.

The underlying structure of the economy is determined by two equations. The first is an expectations-augmented Phillips curve linking the output gap to the inflation rate:

$$\pi_t = \pi_t^e + \kappa y_t + \omega_t, \tag{1}$$

where π_t is the actual rate of inflation, π_t^e is the private sector's inflation expectation for the current period, y_t denotes the period t output gap, $\kappa > 0$ is a known parameter, and ω_t is a mean zero supply shock with known support $[\underline{\omega},\ \overline{\omega}]$. The output gap is defined as the deviation of output from the natural rate y_n; i.e., $y_t \equiv y_t/y_n - 1$. This equation differs slightly from the standard New Keynesian Phillips Curve in that the expectation of inflation is for the current period's inflation rate and not for inflation one period ahead. This change was made in the interest of simplicity; the non-dynamic model is easier to solve.[4]

The second fundamental equation of the model is an IS curve specifying the output gap as a decreasing function of the real interest rate:

$$y_t = \alpha - \beta r_t + \epsilon_t, \tag{2}$$

where r_t is the real interest rate, $\alpha > 0$ and $\beta > 0$ are known parameters, and ϵ_t is a mean zero demand shock with known support $[\underline{\epsilon},\ \bar{\epsilon}]$.

Rewriting equation (1) as $y_t = \kappa^{-1}(\pi_t - \pi_t^e - \omega_t)$, we have that in the absence of nominal rigidities (i.e., as κ approaches infinity), $y_t = 0$ and so from equation (2) $r_t = \alpha/\beta + \epsilon_t/\beta$. Therefore, $\alpha/\beta + \epsilon_t/\beta$ equals the *natural rate of interest*: the equilibrium real interest rate absent nominal rigidities (Woodford 2003, Chapter 4). Accordingly, the expected value, the ratio α/β, coincides with the long-run or average natural rate of interest. Like the Phillips curve, equation (2) is also similar to but different from the IS curves common in the New Keynesian literature. Specifically, our IS curve depends only on current quantities and lacks in particular an expectation of the future output gap on the righthand side; again, this choice is made for simplicity. The real interest rate, r_t, is set exogenously by the central bank.[5]

There are two types of players in the experiment, a central banker and one or more private sector agents. The timing of moves is as follows. At the beginning of each period, before the exogenous shocks have been realized and before the central bank has set monetary policy, the private sector forms its expectations about the rate of inflation that will ultimately prevail in that period. Next, the central bank observes the private sector's inflation expectations and learns the values of the two exogenous shocks for the period. With all of this information, and knowledge of equations (1) and (2), the central bank then sets the real interest rate, r_t, for the period. Given the central bank's choice for the real interest rate and the realization of the demand shock, the IS equation determines the value of the output gap. Given the output gap, expected inflation, and the realization of the supply shock, the inflation rate is determined by the Phillips curve. The period is then declared over and all players are informed of expected inflation, the realizations of the two shocks, the interest rate chosen by the central bank, and the actual values of inflation and the output gap for the period.

While central bankers in the experiment have discretion to set the interest rate, it is worth characterizing the optimal monetary policy in the theoretical model. We assume that the central bank seeks to minimize a standard quadratic loss function:

$$L^{\text{CB}} = (\pi_t - \pi^*)^2 + \lambda y_t^2, \tag{3}$$

where π^* denotes the target inflation rate, which is assumed to be positive. Note that the implicit target for the output gap is 0. The loss function represented in equation (3) is common in the monetary policy literature (Froyen and Guender 2007, Chapter 7; Walsh 2010, Chapter 7). The parameter λ is the relative weight given to output gap deviations. For a central bank like the Federal Reserve with a dual mandate, λ would be positive. For a central bank with a pure inflation targeting mandate, λ would be equal to zero.

Since the private sector forms its expectations for inflation before the central bank sets the interest rate, optimal policy depends on expected inflation. To find the optimal policy conditional on the private sector's inflation expectations and the two shocks, use equation (1) to substitute inflation out of the loss function:

$$L^{\text{CB}} = (\pi_t^e + \kappa y_t + \omega_t - \pi^*)^2 + \lambda y_t^2. \tag{4}$$

The value of the output gap that minimizes (4) is:

$$y_t^{\text{OPT}} = \frac{\kappa}{\kappa^2 + \lambda} \left(\pi^* - \pi_t^e - \omega_t\right), \tag{5}$$

where y_t^{OPT} denotes the optimal value of the output gap conditional on the private sector's inflation expectations. Note that y_t^{OPT} will differ from the rational expectations equilibrium output gap when the private sector does not set inflation expectations rationally. Next, from equation (2), use the conditionally optimal output gap to find the conditionally optimal interest rate:

$$r_t^{\text{OPT}} = \frac{\alpha}{\beta} + \frac{1}{\beta}\epsilon_t - \frac{\kappa}{\beta(\kappa^2+\lambda)}\left(\pi^* - \pi_t^e - \omega_t\right). \tag{6}$$

The optimal interest rate policy conforms with conventional understanding about stabilization policy: the central bank should raise the interest rate, r_t, relative to the long-run natural rate α/β, in response to positive demand and supply shocks. Also, note that the supply shock ω_t and the difference between expected inflation and the inflation target enter equation (6) symmetrically. A one percentage point increase in inflation expectations above the inflation target is equivalent to a one percentage point exogenous shock to the Phillips curve. This observation motivates us to run the experiment *without* supply shocks since fluctuations in the private sector's inflationary expectations function like supply shocks.

Next, we characterize the optimal formation of inflation expectations. The private sector chooses its inflation expectation, π_t^e, to minimize its own loss function,

$$L^{\text{PS}} = (\pi_{t|t_0} - \pi_t^e)^2, \tag{7}$$

where

$$\pi_{t|t_0} = \pi_t^e + \kappa y_t, \tag{8}$$

is the inflation rate given the information available about the supply shock at the beginning of period t; i.e., before values for the exogenous shocks ω_t and ϵ_t have been realized. The private sector has complete knowledge of the central bank's optimization problem including the conditionally optimal output gap in equation (5). So using equation (5) to eliminate the output gap from the private sector's loss function yields:

$$L^{\text{PS}} = \left[\frac{\kappa^2}{\kappa^2+\lambda}\left(\pi^* - \pi_t^e\right)\right]^2. \tag{9}$$

In the rational expectations equilibrium, the private sector expects that the central bank will meet its inflation target at each date:

$$\pi_t^e = \pi^*. \tag{10}$$

Substituting (10) into equation (5) yields the unique rational expectations equilibrium value of the output gap:

$$y_t^* = -\frac{\kappa}{\kappa^2 + \lambda}\omega_t. \tag{11}$$

From the optimal interest rate setting given by equation (6), the unique rational expectations value of the interest rate is:

$$r_t^* = \frac{\alpha}{\beta} + \frac{1}{\beta}\epsilon_t + \frac{\kappa}{\beta(\kappa^2 + \lambda)}\omega_t. \tag{12}$$

Intuitively, under the optimal policy, the central bank sets the interest rate at the long-run natural rate level, α/β, which closes the output gap in the non-stochastic equilibrium, with adjustments to offset the effects of demand and supply shocks.

CLASSROOM EXPERIMENT

To implement this model as a classroom experiment, we followed the approach of several experimental papers on this topic (Arifovic and Sargent 2003, Duffy and Heinemann 2018) and divided participants into two player types: central bankers and private sector agents. In the classroom experiment we report on, we chose to consider economies consisting of groups of five players. Within each economy, one student was chosen to be the central banker and the other four students played the role of private sector agents. Nevertheless, many other configurations of groups (economies) are possible. For instance, one could have a single private sector agent or many more than four private sector agents in each group. One could also have more than one central banker in a group, as in actual monetary policy committees, and these players (committee members) would have to talk with one another to reach consensus.

Our sample consisted of 150 students taking one of three undergraduate courses in intermediate macroeconomics at UC, Irvine. The 150 student sample resulted in 30 groups of size 5, with 14 groups (70 students) assigned to the dual mandate treatment and the remaining 16 groups (80 students) assigned to the inflation targeting treatment.

While the student subjects had been studying macroeconomics, they had not previously seen the model of this experiment; it was the next topic to be addressed in the course. Students earned extra credit for participating in the study, which took place in several sessions over the course of a couple of days outside of regular lecture. The experiment began with students seated at computer terminals. Written instructions were handed out and read aloud. The instructions for each treatment are included in the Appendix.

After students had read the instructions, there was a time for clarifying questions to be asked, after which the experiment began. Students made decisions on their computer terminals when prompted to do so. The experiment we implemented in the laboratory was programmed using the software z-Tree [6]

A total of 10 periods were played by each group. The entire experiment, including the reading of instructions and the play of the 10 periods was completed in less than an hour. Some additional time should be budgeted for a discussion – for suggestions, see the section “Discussion” below. Alternatively, if time allows, the experiment can be conducted in one class meeting and discussed, along with a presentation of the model and the results, in the next class meeting.

The timing of moves is described in the instructions, but we provide a brief summary here. In each of the 10 periods, each private sector player i forms a forecast of the inflation rate for period t in percentage terms. When forming inflation forecasts, the private sector players have full knowledge of the equations of the model; specifically equations (1) and (2). They also know that the exogenous supply and demand shocks ω_t and ϵ_t are mean zero with bounded supports but they are not informed of the realizations of either of these two shocks until the end of the period. Private sector players are instructed that their payoffs in points depends on how accurately they guess the inflation rate, as in (7), a feature that is public knowledge to all players, including the central bank. Specifically, private sector players are instructed that their payoff function in points is given by:

$$10 - (\text{My Inflation Forecast} - \text{Inflation})^2, \tag{13}$$

Here, "My Inflation Forecast" is player i's own forecast of the inflation rate that she thinks will prevail in period t – denote this by $\pi^e_{i,t}$ – while the actual realized inflation rate, "Inflation" is the inflation rate, π_t, as determined by equations (1) and (2) from the previous section and using the central bank player's choice for r_t. Further, all players are instructed that the private sector's inflation forecast used in the model, π^e_t, will be the *average* of the four private sector agents' forecasts, i.e., $\pi^e_t = \frac{1}{4}\sum_{i=1}^{4}\pi^e_{i,t}$, but that each private sector player's own payoff in points will depend on the extent to which his or her own, individual inflation forecast, $\pi^e_{i,t}$ differs from the realized inflation rate, π_t.[7]

After all private sector agents have formed their inflation forecasts, the central bank player is presented with the average of these forecasts, π^e_t. The central bank player then learns the realizations of the supply and demand shocks, ω_t and ϵ_t. We recommend that the values of ω_t and ϵ_t be the same for all groups to make comparisons across groups (economies) easier to comprehend. The central bank player is then tasked with choosing the real interest rate r_t, again with full knowledge of the model. The central bank player's payoff function in points is known to both the central bank and private sector players and is given by:

$$20 - (\text{Inflation} - \pi^*)^2 - \lambda \times (\text{Output Gap})^2, \tag{14}$$

in the dual mandate treatment regime and by:

$$20 - (\text{Inflation} - \pi^*)^2, \tag{15}$$

in the inflation targeting regime.[8] These quadratic loss function objectives are consistent with the theoretical objectives of the theory presented in the previous section. As in the model, the inflation target is π^* and the output gap target is zero, and these are perfectly known to both the central bank and the private sector players.[9] We presented these loss function objectives to players and explained that private sector agents could get a maximum of 10 points per period while central bankers could get a maximum of 20 points; the point discrepancy was due to the harder task faced by central bankers.[10] "Earnings" from the experiment are calculated as the sum of payoff points from all periods played.

Model Parameterization

For the classroom experiment we report in the "Results" section below, we chose the following parameterization of the model. For the New Keynesian Phillips Curve (1), we set $\kappa = 0.25$. This value for κ is slightly larger than the estimated or calibrated values typically found in the literature.[11] In doing so we follow Mankiw (2016) who also uses the same value in his Phillips curve calibration. We chose not to have a supply shock, i.e., we set $\omega_t = 0$ for all t to simplify the central bank player's problem and because (as previously noted) endogenous variations in the private sector's inflationary expectations, π_t^e, provide another type of noise for equation (1). For the IS equation (2), we set $\alpha = 2$ and $\beta = 1$, so that in the absence of any noise, the long-run natural interest rate would be $\alpha/\beta = 2$. The mean zero demand shock, ϵ_t, was a uniform random draw over the interval $[-1.25,\ 1.25]$, with a new draw being made with replacement in each period. Our computer program draws this shock process in advance, and all groups within a session face the same shock realizations in each period. For the central bank's objective function, we set the target inflation rate $\pi^* = 2.5$ in both the dual mandate and inflation targeting regime cases. In the dual mandate regime, we set the relative weight on the output gap, $\lambda = 0.1$, which is in the range of estimated values for the U.S.[12] These parameter choices were all made known to subjects in the written instructions; see the Appendix for details. With this parameterization, the rational expectations equilibrium prediction is $(\pi_t^e,\ y_t^*,\ r_t^*) = (2.5,\ 0,\ 2 + \epsilon_t)$.

Paper and Pencil Implementation

We recognize that implementation of the program using networked computers is not always feasible, and so we also briefly describe how the experiment could be carried out using paper and pencil (P&P) and a calculator or electronic spreadsheet. For a P&P implementation, participants would again be given written instructions of the type found in the Appendix, but modified so that their choices are written on record sheets that are passed back and forth. An example of such record sheets, one for private sector players and one for central bank players, is provided in Table 1.

[INSERT TABLE 1 ABOUT HERE]

As in the computerized experiment, private sector agents would move first, forming expectations of inflation for the current period and writing down their expectations on their record sheets, which identifies each person by ID and group number. These record sheets would then be passed to the instructor, who would then average each group of private sector players' expectations for inflation using a calculator or spreadsheet to arrive at a single value, π_t^e, for each group. Alternatively, one could just have one private sector player matched with each central banker for all periods, avoiding the need to average inflationary expectations.[13] The instructor then informs the central banker of the private sector's inflation expectation, π_t^e, for his group, and of the realizations of the demand and/or supply shocks for the period ϵ_t and ω_t, which are written down on the central bank's record sheet. The shocks could be pre-drawn using a random number generator, or they could result from having subjects roll one or more die, with a table converting die roles into shock realizations. With knowledge of expected inflation, the demand shock, the supply shock, and the equations of the model, the central banker adds to this record sheet his or her choice for the interest rate for the period, r_t. The instructor then collects the central bankers' record sheets and uses π_t^e, ϵ_t, ω_t, and r_t to compute y_t and π_t for each group as well as the points earned by the central banker and the individual private sector agents. This information would be recorded on each student's record sheet and these sheets would then be returned to the players. Alternatively, the instructor could simply tell each group of private sector agents the interest rate chosen by their central banker and allow students to complete the remaining columns of their record sheets. The process can be completed for as many periods as time allows. A less cumbersome variation of the procedure described above would be to have a representative group of perhaps five or so players make decisions in front of the entire class, with the calculations made by the instructor using a spreadsheet projected onto a screen for all to see, which would speed up the feedback process. Of course, the experiment can also be easily programmed up using the software of one's own choosing.

RESULTS

Figure 1 depicts the outcomes in the experimental economies grouped by monetary policy regime (dual mandate or inflation targeting). In the figure, each light solid line corresponds to a single group of five. The dark dashed lines are the averages for all groups in a given policy regime. The top panel shows the outcomes for the 14 groups with dual mandate central banks. The bottom panel shows the outcomes for the 16 groups with inflation targeting central banks. The variety in outcomes across the groups in each treatment is interesting because the rational expectations equilibrium is the same for all groups. Groups in different sessions received different demand shock draws, but since the number of groups is large relative to the number of sessions, differences in shock history accounts for only a little variation in cross-group outcomes.[14] The outliers are also interesting: one group exhibited exceptionally high expected inflation beginning in period 4; as a consequence, the group endured substantially higher actual inflation and a lower output gap as the central banker struggled to stabilize the economy through a high interest rate policy. These efforts were yielding some payoff by period 10 of the experiment. We discuss this particular group in more detail below.

[INSERT FIGURE 1 ABOUT HERE]

Comparison of the two panels of Figure 1 reveals striking differences. The groups in the inflation targeting regimes showed substantial convergence over time. In the first period of the experiment, the real interest rate, the output gap, and expected inflation varied widely across groups.

Over time however, these values converged toward a much smaller range of values. The greater degree of convergence among the inflation targeting groups is more apparent in Figure 2 which plots only the averages of the groups in each regime.

[INSERT FIGURE 2 ABOUT HERE]

Figures 3 through 7 present individual outcomes for select groups. The figures show the realizations of the real interest rate, inflation, the output gap, and the inflation forecast error (solid lines). For comparison, we also show the rational expectations equilibrium values (dashed lines) and the values that would result if the central bank set policy optimally, conditional on expected inflation (dotted lines). Note that regardless of regime, the rational expectations equilibrium entails a perfectly stabilized inflation rate and output gap because we turned off exogenous supply shocks.

Among the groups with an inflation targeting regime, 7 of 16 (44 percent) converged to the rational expectations equilibrium. Figure 3 depicts the time series for one such group. In the early periods, the central bank did not set the real interest rate high enough to stabilize inflation and in the second period, the central bank over-compensated in the other direction. But by period five, the central bank managed to perfectly stabilize the inflation rate and by period six, output gap fluctuations were also brought under control. By period nine, the private sector inflation forecast error was essentially at zero.

[INSERT FIGURE 3 ABOUT HERE]

By comparison, Figure 4 depicts the experience of a group in an inflation targeting regime that did not find its way to the rational expectations equilibrium. Starting from period 2, the central bank perfectly implemented the 2.5 percent inflation target meaning that the central bank was setting the interest rate optimally given expected inflation. However, in this case, the private sector was unable to catch on to the central banker's unyielding commitment to the optimal policy leading to a consistently high inflation forecast error. The persistent inflation forecast error drove the output gap below zero. In a dual mandate regime, the central banker would have faced a trade-off in stabilizing inflation and the output gap, but for this inflation targeting regime group, the central banker had no problem meeting his/her single objective. In a post-experiment discussion, one can discuss with the private sector members of the group why they consistently expected the wrong inflation rate and how their performance could have improved.

[INSERT FIGURE 4 ABOUT HERE]

By contrast to the groups with inflation targeting central banks, the groups with dual mandate policy regimes did not converge as clearly to the rational expectations equilibrium of the model. While a few of the dual mandate groups managed to get close to the rational expectations equilibrium by period 10, none of the groups appeared to move toward that equilibrium as deliberately and smoothly as the inflation targeting group represented in Figure 3.

Figure 5 depicts the outcome for one of the two dual mandate groups that managed to get the closest to the rational expectations equilibrium. Throughout the middle part of the experiment, the central bank consistently kept the interest rate too low and therefore allowed the inflation rate to rise to a peak of almost 3.5 percent in period 6. Interestingly though, the private sector's inflation forecast error was not off by more than half of a percentage point. In the final rounds of the game, the central banker managed to bring the inflation rate back down so that by period 10, the economy was close to the rational expectations equilibrium. Of course, it's not clear that the economy would have stayed in that equilibrium if the game had been allowed to proceed further.

[INSERT FIGURE 5 ABOUT HERE]

Figures 6 and 7 depict two dual mandate groups that did not converge to the rational expectations equilibrium. In Figure 6, the central bank consistently kept the real interest rate too low given the private sector's inflation expectations allowing the inflation rate to rise steadily over the experiment. Interestingly, in spite of the central banker not playing optimally, the private sector appeared to catch on and the inflation forecast error was small relative to the inflation rate. A result like this would create a nice opportunity to bring up the high and rising inflation in the US through the 1960s and 1970s.

[INSERT FIGURE 6 ABOUT HERE]

[INSERT FIGURE 7 ABOUT HERE]

In Figure 7, a member of the private sector of the group depicted entered an expected inflation rate of 50 percent in period 4. In so doing, the player created a strong negative supply shock that put upward pressure on the inflation rate and downward pressure on the output gap. The central bank did an excellent job responding to this shock: the inflation rate and output gap closely followed the values that would minimize the central bank's loss given the shock to inflation expectations. In subsequent periods, the player who created the shock submitted more reasonable inflation forecasts, but the shock still had a persistent effect on inflation because the other private sector members temporarily increased their own expectations in response to their own period 4 forecast errors. By the end of the session, the effect of the shock had essentially dissipated. While this episode was likely created by a student that was not taking the exercise seriously or who made a one-time mistaken entry, the outcome is still interesting and would make for a good discussion.

Tables 2(a) through 2(c) show that between the first and second halves of the game, the variability in outcomes across groups falls substantially more for groups operating under the inflation targeting regime than for groups operating under the dual mandate regime. Apparently, inflation targeting groups learn faster over the course of playing the game. The degree of learning over the course of the game is particularly evident in the behavior of the central banks. Figure 8 shows the average performance of the dual mandate and inflation targeting central banks over time, as measured by the loss function for the dual mandate central banks. While starting out higher, the loss for the inflation targeting central banks fell rapidly and ended up lower than the loss for the dual mandate central banks, suggesting that the inflation targeting central banks learned how to play better than their dual mandate counterparts.

[INSERT TABLE 2 ABOUT HERE]

[INSERT FIGURE 8 ABOUT HERE]

DISCUSSION

To help students get the most from the experiment, instructors should consider complementing the experience with an in-class discussion of the results and perhaps also with some homework. Based on our own experience, we suggest the following approach consisting of one lecture period and a homework assignment.

1. First half of lecture: Run the experiment. In our experience, 10 repetitions of the experiment can be run in about 30 minutes, including the reading of the instructions.

2. Second half of lecture: Analyze the optimal policy problem and debrief students on the results of the experiment.

3. Homework assignment: Students use a spreadsheet to compute the rational expectations equilibrium values of inflation, the output gap, and the real interest rate using the same shocks from the experiment. As part of the assignment, students could be asked to plot the data from the experiment against these rational expectations values.

The choice of when exactly during the course to run the experiment will depend on the preferences of the instructor. In our experience, a good time to conduct this experiment is after students have learned to analyze equilibrium in a short-run model with an IS curve and a Phillips curve. Our experimental evidence also suggests that running the experiment with an inflation targeting regime (as opposed to the dual mandate regime) is likely to increase the number of groups that find the rational expectations equilibrium within a short period of time. However, if the experiment were to be run in a money and banking course to teach the merits of inflation targeting, then dividing the class into dual mandate and inflation targeting treatment groups would also be of interest.

The experiment produces a lot of data. It may be useful to conduct the experiment in the latter half of one class and defer discussion of the results to the first half of the following class in order to give the instructor time to review the results and to create a presentation with graphs. Alternatively, as noted above, the task of graphing the data could also be given to the students as part of their homework assignment. Students could be told their group number and asked to graph the data against the equilibrium prediction for their group only.

In the discussion that follows the experiment, the instructor should review the basic components of the theoretical model and walk the class through how to solve for the rational expectations equilibrium. Then, the instructor could lead the class through a discussion of the results from the experiment. This discussion should emphasize that the range of outcomes across the different groups is due entirely to player variation (as shock realizations are the same across all groups). A graph like those shown in Figure 1 would be a helpful visual aid for this purpose.

The discussion should also walk students through the results for each group with students being asked to verbally suggest explanations for the results and offer suggestions for how the private sector or central bank could have improved their performance. Again, visual aids will be helpful here. The graphs in Figures 3 through 7 are probably too complicated for a classroom discussion. Instead, we suggest a simpler approach: for each group, make four graphs showing the time series for: 1) expected inflation, 2) actual inflation, 3) the output gap, and 4) the real interest rate. Plot the group-specific values together with the rational expectations equilibrium prediction. Figure 9 depicts such an example for one group of 5 players in our inflation targeting treatment.

[INSERT FIGURE 9 ABOUT HERE]

To lead the discussion of a specific group's results, we suggest the following process:

1. In period 1, the private sector expected inflation to be [value] and the central bank set the interest rate at [value]. How do these two values explain the observed values of the output gap and inflation in period 1?
2. Did the group reach the rational expectations equilibrium by the end of the experiment? How can you tell?
3. If the group did not reach the rational expectations equilibrium:

(a) Why does it look like the group was unable to reach the rational expectations equilibrium?

(b) What, if anything, should the private sector have done differently?

(c) What, if anything, should the central banker have done differently?

For example, consider the group under the inflation targeting regime whose results are depicted in Figure 9. In period 1 the private sector expected the inflation rate to be about 5 percent. Given the demand shock, the central bank set the real interest rate to close the output gap. With the output gap equal to zero, actual inflation equaled expected inflation. The group did not eventually converge on the rational expectations equilibrium. From period 2 on, the central bank succeeded in choosing interest rates that made the inflation rate equal to the target value, consistent with its inflation targeting objective. While the central bank succeeded in anchoring inflation at the target value of 2.5 percent, the private sector consistently expected an inflation rate around 4 percent creating a persistently negative output gap. The private sector could have improved its performance by observing that inflation was well-anchored at 2.5 percent.

If students are competent in using spreadsheets, the instructor could ask the students in a homework assignment to use a spreadsheet to compute the rational expectations equilibrium values of inflation, the output gap, and the real interest rate using the same shocks from the experiment. This exercise would reinforce the lessons learned from the experiment by giving students an opportunity to go back to the original shocks and demonstrate that they know how their group should have played in the experiment. They could further plot the deviation of actual inflation, the output gap and the real interest rate from the rational expectations values to determine whether these deviations decreased with experience.

There are several pedagogical benefits from incorporating the experiment into an intermediate macroeconomics course. First, the experiment gives students hands-on experience with a serious monetary policy model. Students can calculate the equilibrium of the model and explore how these predictions differ from the experimental data. Second, a key lesson from this experiment is the critical role of the central bank in anchoring inflationary expectations. Since some participants have to form inflationary expectations and the central bank player has to respond to these expectations, the lesson goes beyond abstract arguments about expectations management and results in real, cause-and-effect understanding of this expectations anchoring role.[15] Finally, the data generated for the artificial economies provides excellent source material for classroom discussion. A course instructor can lead the class through a critical analysis of the outcomes. If, for example, a group suffered from persistently high inflation, the course instructor could help students to infer from the data whether the cause was consistently loose monetary policy or perhaps irrationally high inflation expectations.

Another pedagogical benefit of the experiment is that students can easily be assigned to either groups with dual mandate central banks or groups with inflation targeting central banks. The benefit is that the experiment can be used to help students understand some of the arguments for inflation targeting. Beginning in 1989 with the Reserve Bank of New Zealand, more than 25 countries have since adopted inflation targeting monetary policy regimes (Walsh 2009, Roger 2010).[16] In contrast, the Federal Reserve is unique in having an explicit dual mandate for stabilizing inflation and the real economy (Bank for International Settlements 2009). Our results suggest that students find it easier to understand the game in the inflation targeting environment and this lesson, by analogy, can help students understand the apparent widespread appeal of inflation targeting.

Another point of discussion might concern the debate over rules versus discretion in central bank policymaking. In the experiment described in this paper, the central bank has complete discretion in setting the interest rate in each period. Discretion has benefits and costs. On the one hand, discretionary policy allows the central bank the flexibility to respond to inflationary expectations and demand and supply shocks. On the other hand, replacing the central banker with a policy rule for setting the interest rate such as Taylor's rule (Taylor 1993) might improve the credibility of policymaking, yielding less variable outcomes for the output gap, inflation and and inflationary expectations. After completing this experiment, students may have some greater appreciation for the rules versus discretion debate.

Finally, we note that students playing as inflation targeting central bankers appeared to comprehend their policy role more quickly resulting in faster average central bank decision times for the inflation targeting groups in the latter periods of the experiment.[17] In Figure 10 we plot cumulative densities for average central bank decision time splitting groups by central bank regime (dual mandate or inflation targeting). The left panel depicts the cumulative densities of decision times for the first 5 periods of the experiment and the right panel depicts these same densities for the final 5 periods. In the first 5 periods, the dual mandate central banks were clearly making decisions faster (but not necessarily better) than the inflation targeting central banks. It took about 90 seconds for all dual mandate central banks to enter their interest rate decisions as compared with the 115 seconds needed for all inflation targeting central banks.

[INSERT FIGURE 10 ABOUT HERE]

By the second half of the experiment (last 5 periods), central banks in both regimes showed substantial reductions in average decision times. The time needed for all dual mandate central banks to enter a decision fell by about 32 seconds while the time needed for all inflation targeting central banks to enter a decision fell by 65 seconds. While central banks in both regimes showed improved speed in decision-making, the inflation targeting central banks showed the greatest improvement and this is apparent from the steepening of the density for inflation targeting groups relative to the density for dual mandate groups. We have already seen that groups with inflation targeting central banks were more likely to converge to the rational expectations equilibrium. Figure 10 reveals that inflation targeting central banks were not just closer to pursuing the optimal policy, they were also able to do so more quickly.

EXPERIMENTAL VARIATIONS

We consider two variations on the experiment described in the previous section, which explore the robustness of our findings to other New Keynesian model settings. In the first variation, we again consider the case where there are four private sector agents and one central banker who operates under the inflation targeting regime, but we draw the exogenous demand shocks from a normal distribution with mean 0 and variance 0.25 instead of from a mean zero, uniform distribution over the interval $[-1.25, 1.25]$.[18] The aim of this change was to explore whether a more tightly centered distribution of demand shocks around the mean of 0 might aid the central banker in stabilizing inflation and thus inflationary expectations. In the paper and pencil version, the normally distributed shocks could be pre-drawn using a random number generator, or could be approximated by having participants roll several dice (more is better), summing the total and using a table to convert these sums into shock realizations. However it is done, one should take care to explain to participants what it means for shocks to be normally distributed (see our experimental instructions for our approach), as this may not be as clear as in the case of uniformly distributed shocks.

Figure 11 compares inflation outcomes for inflation targeting groups facing normally versus uniformly distributed demand shocks. The groups with normally-distributed demand shocks experience inflation that is less volatile and closer to the target, on average. It is not clear whether this change in inflation is owing to the change in the shock distribution (which becomes less volatile), or whether the change in the shock process also enabled better decision making by the central bank players. Still, the message is clear that with the prospect of less extreme demand shocks, inflation is better stabilized.

[INSERT FIGURE 11 ABOUT HERE]

In a second variation, we retained the normally distributed shock process, $\epsilon_t \sim \mathcal{N}(0,\ 0.25)$, and we made two more substantial modifications to our model. First, we replaced the student playing the central bank with a robot player. Thus, instead of five players in each group there were only four and all four were private sector players tasked with correctly forecasting inflation as in our original design. The robot central bank player was known (by the private sector human subject players) to implement monetary policy according to the following Taylor policy rule:

$$r_t = \frac{\alpha}{\beta} + \varphi_\pi \left(\pi_t - \pi^*\right) + \varphi_y y_t, \tag{16}$$

where $\varphi_\pi = 1.5$, $\varphi_y = 0$, and $\alpha/\beta = 2$ is the long-run natural rate of interest. The aim of this change is to explore the impact of rule-based policy on inflation and output stabilization. The Taylor rule (Taylor 1983) is the most prominent of such policy rules, and including this case can lead to discussion of the debate about rules versus discretion in monetary policy. In our experiment we set $\varphi_y = 0$ to facilitate comparisons with our pure inflation targeting regime involving human central bankers.

A second change we made was to introduce inflation persistence into the Phillips curve:

$$\pi_t = \gamma\pi_{t-1} + (1-\gamma)\pi_t^e + \kappa y_t + \omega_t, \tag{17}$$

where $\gamma \in [0, 1]$ reflects the degree of persistence of inflation and π_{t-1} is actual inflation in the previous period. Note that this change transforms our model from a static to an explicitly dynamic environment. To explain the role of γ to students, we told them that a fixed share, γ, of players simply expect that inflation this period will be whatever it was in the previous period, while the remaining fraction, $1-\gamma$ forecast inflation anew each period. We set γ to 0.5 in the experiment which is close to the estimate reported by Galí and Gertler (1999) using field data. The expectation of inflation for period t, π_t^e, remains determined by the average of the four private sector agents' forecasts. For period $t = 1$ we set $\pi_0 = 2.5$, which is the target value, π^*, in our experiment. Our software allows for many other configurations, including setting $\gamma = 0$ as in our original (static) experiment or giving some weight to the output gap, ($\varphi_y > 0$) in the policy rule.

Recall that Figure 11 compares the inflation outcomes for the inflation targeting groups with normal shocks (our first new variant) against inflation generated by inflation targeting groups facing uniform shocks. Figure 12 shows inflation in the groups facing the modified Phillips curve together with a robot central banker following the Taylor rule (our second new variant). As these figures reveal, there is less variability in inflation outcomes with normally distributed shocks as opposed to uniformly distributed shocks, and considerably less variability in inflation in groups with the modified (more persistent) Phillips curve and Taylor rule for monetary policy. Indeed, the latter finding should not be too surprising, since rule-based monetary policy should help to contain inflation expectations as long as the Taylor principle is satisfied. Further, lagged inflation in the Phillips curve attenuates the effect of current-period shocks on inflation which also helps to smooth inflation over time.

[INSERT FIGURE 12 ABOUT HERE]

STUDENT EVALUATION OF THE EXPERIMENT

Following the suggestion of a referee, we surveyed some intermediate macroeconomics students who participated in the experiment in the Spring term of 2018. Out of 65 students surveyed, 26 responded (40%). All but one of the respondents were majoring in one of the three majors offered by the economics department. 17 were juniors, 5 were seniors, and 4 were sophomores. The survey responses were anonymous. Responses are summarized in Table 3.

[INSERT TABLE 3 ABOUT HERE]

Survey respondents overwhelmingly indicated that they enjoyed the experiment with 96% answering "Yes" to the question "Did you enjoy the experiment?" 73% of respondents indicated that they think that the experiment should be incorporated into intermediate macroeconomics courses at UC, Irvine. Furthermore, 81% agreed that students would better understand the IS-MP model of monetary policy and aggregate demand if the experiment were to be incorporated into intermediate courses level courses at UC, Irvine. Together these results suggest that students both like the experiment and think it provides pedagogical value. In the future, it would be of interest to evaluate the impact of this experiment on student retention of the material, as reflected in standardized tests or homework scores.

CONCLUSION

The experiment we have developed and reported on provides a clear demonstration of a workhorse model of monetary policy, the New Keynesian model. Students are assigned roles as either central bankers or private sector agents. Both make decisions that impact on inflation and output. The experiment will enliven classroom discussions of how central bankers make policy decisions and how private sector expectations matter in that process. The experiment also clearly illustrates the difficulties a central bank may face in trying to stabilize two quantities, inflation and the output gap, using only a single instrument, the interest rate, as in the dual mandate regime. By comparison, learning of the equilibrium appears to be faster in the simpler inflation targeting regime, and faster still if the central banker is replaced by a policy rule satisfying the Taylor principle. The experimental behavior is also interesting for illustrating that it can take some time to achieve the rational expectations equilibrium. After participating in this experiment, students will better understand why the job of the central bank is often characterized as managing and anchoring expectations.

NOTES

[1]Contemporary textbooks by Chugh (2015), Mankiw (2016), Mishkin (2016), and Jones (2017) each include business cycle models with some incarnation of the expectations-augmented Phillips curve.

[2]Resources for running the experiments described in this paper including z-Tree programs along with data and programs for reproducing our figures and statistics are available at:

https://github.com/letsgoexploring/monetary-policy-game.

[3]Link: http://people.whitman.edu/~hazlett/econ/

[4]In addition, as the game is played repeatedly, students can learn from past realizations of inflation to form more accurate forecasts of inflation in the current period.

[5]In practice, central banks set the nominal interest rate. But since expected inflation in our framework is determined before the central bank sets policy, the Fisher equation implies that the central bank implicitly sets the real interest rate with its choice for the nominal interest rate. Therefore, for simplicity, we assume that the central bank directly sets the real rate.

[6]See Note 2 for a link to our GitHub repository that contains software and instructions for running the experiments with z-Tree.

[7]The task faced by the private sector players constitutes a "learning–to–forecast" experimental design. See Hommes (2011) for a survey of other experiments using this approach.

[8]As an alternative to the inflation targeting regime's objective function, it might also be of interest to consider a price level targeting regime by changing the central bank's loss function to: $20 - \frac{1}{T}\sum_{t=1}^{T}(\pi_t - \pi^*)$, where T is the current period of the experiment. This regime allows for periods of inflation below (above) the target value provided that they are later matched by periods above (below) the target value, which works to better stabilize the level of prices, but can lead to greater volatility in the inflation rate.

[9]Such knowledge facilitates computation of the rational expectations equilibrium. One could relax this assumption, for instance, by making the central bank's targets for inflation and the output gap private information (known only to the central bank) that the private sector would have to learn over time.

[10]We note further that while the quadratic loss functions admit negative point earnings, our program truncated the point formula at zero, so that no subject actually earns less than zero points.

[11]For example, Givens (2012) estimates the coefficient on output in a New Keynesian Phillips Curve to be about 0.05 while Ireland (2004) calibrates the value to 0.1

[12]In a calibrated model, Woodford (2003b) obtains a weight of 0.048 on output gap fluctuations in the loss function but Givens (2012) estimates values between 0.0987 and 0.1351 while Givens and Salemi (2015) estimate values between 0 and 0.5667.

[13]A disadvantage of the latter design is that inflation expectations may be widely varied, at least initially.

[14]Our program chooses one set of demand shocks for all groups in a given session. Each session consists of between 4 and 6 groups. Thus, while there is some variation in demand shocks, there is not as much variation in these shocks as there are groups of players.

[15]According to Former Federal Reserve Chairman Ben S. Bernanke, inflation expectations are "anchored" if they are "relatively insensitive to incoming data" (Bernanke 2007).

[16]Some central banks, like the Bank of Korea and the Reserve Bank of New Zealand, pursue strict inflation targeting policies while others, like the European central bank and the Bank of England, follow a hierarchical regime in which meeting an inflation target is a primary goal that takes priority over other stabilization objectives.

[17]Our program computes decision time from the moment that the central bank player receives the private sector inflation forecast to the time that central banker submits his/her interest rate choice.

[18]Under our parameterization for the normally distributed demand shocks, 98.8% of all realizations will lie within the interval $[-1.25, 1.25]$, making the extreme values comparable to the uniform shock case, though the normally distributed errors will, of course, be more tightly concentrated around 0.

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APPENDICES

EXPERIMENT INSTRUCTIONS

Instructions for Dual Mandate Treatment

Welcome to this experiment in the economics of group decision-making.

In today's session, you will participate in a number of periods of a group decision-making task.

Prior to the start of the very first period, you will be randomly assigned to a group of size 5. Within this 5-player group, 4 players will be assigned the role of "private sector" players. The objective of each private sector player is to correctly forecast the inflation rate in each period. The remaining 5th player in each group is assigned the role of the government's "central bank". The central bank's objective is to set the interest rate in each period in such a way that he or she minimizes deviations of inflation and output from certain benchmarks (as discussed in detail below). The roles of the five players in each group will remain fixed over all periods of the experiment.

The timing of moves and the choices to be made each period

In each period, the private sector players move first. Each forms a forecast of the inflation rate for the period. Specifically, each private sector player is asked "What do you think inflation will be this period?" If you are a private sector player, you enter your forecast in the box on your computer screen and then click the OK button. Your forecast of inflation should be in percentage terms; if you think inflation will be X%, then enter X, where X is a number. Your forecast can be any real number up to two decimal places. In choosing a forecast, each private sector player's objective is to accurately forecast the actual inflation rate for the period. Specifically, each private sector player's payoff in points is: $10 - (\text{My Inflation Forecast} - \text{Inflation})^2$, where "My Inflation Forecast" is the private sector player's own inflation forecast and the determination of the "Inflation" rate is explained below. After all four private sector players have submitted their forecasts for inflation, the average of these four inflation forecasts is calculated, and this is denoted as "Average Expected

Inflation”. The Inflation rate in each period is determined by the equation:

$$\text{Inflation} = \text{Average Expected Inflation} + .25 \times \text{Output Gap} \tag{18}$$

The first term, Average Expected Inflation is determined by the four private sector players. The “Output Gap” is the difference between actual and potential output (GDP). If actual output is above potential (if the Output Gap is positive), that raises inflationary pressure, while if output is below potential (if the Output Gap is negative) that reduces inflationary pressure. Notice however, that the weight on the Output Gap in determining Inflation is $1/4$ the weight on Average Expected Inflation in determining Inflation.

After Average Expected Inflation is determined, the central bank player learns the value of Average Expected Inflation and must choose the Interest Rate for the period. The central bank’s choice of the Interest Rate directly affects the Output Gap via the equation:

$$\text{Output Gap} = 2 - 1 \times \text{Interest Rate} + E \tag{19}$$

In this equation, “E” is a mean zero demand shock that is a uniform random draw over the interval $[-1.25, 1.25]$. Notice that an Interest Rate greater than 2 leads to an expected negative Output Gap (since the expected value of E is 0) while an Interest Rate less than 2 leads to an expected positive Output Gap. Notice further that once the central bank has set the Interest Rate, then the Output Gap is determined via equation (2) and once the Output Gap is determined, then Inflation is also determined via equation (1). Prior to choosing the Interest Rate for the period, the central bank knows the following information for the period: Average Expected Inflation and the realization of the shock E. After viewing this information, the central bank is asked: “What interest rate do you want to choose this period?” If you are the central bank player, you enter your choice for the Interest Rate in the box on your computer screen and then click the OK button. Your interest rate choice should be in percentage terms; if you want to choose an interest rate of R% then enter R, where R is a real number. You can enter any real number up to two decimal places.

The central bank's payoff function in points is: $20 - (\text{Inflation} - 2.5)^2 - .1 \times (\text{Output Gap})^2$. That is, the central bank's payoff is highest when actual Inflation is exactly equal to a target value of 2.5 and when the Output Gap is exactly equal to a target value of 0. While the central bank must try to achieve these twin objectives each period, it has only a single instrument to do so, namely its choice for the Interest Rate. Notice also that the central bank's loss from missing its Output Gap target of 0 is $1/10$ of its loss from missing its Inflation target of 2.5.

Feedback

At the end of each period, both types of players (private sector and central banks) will learn, or be reminded of: The Average Expected Inflation, the actual Inflation rate, the Output Gap, the central bank's choice of the Interest Rate and the actual realization of the shock E for the period. In addition, all players will learn their payoffs for the period. If the final period has not yet been played, the game will proceed to the next period, where the timing of moves and the choices to be made will be the same. However, in each period, there will be different random draws for the shock E.

Earnings

Your earnings are the sum of your payoff points from all periods played. A private sector player's maximum payoff is 10 points per period while a central banker's maximum payoff is 20 points per period.

Questions

Are there any questions before we begin?

Instructions for Inflation Targeting Treatment

Welcome to this experiment in the economics of group decision-making.

In today's session, you will participate in a number of periods of a group decision-making task. Prior to the start of the very first period, you will be randomly assigned to a group of size 5. Within this 5-player group, 4 players will be assigned the role of "private sector" players. The objective of each private sector player is to correctly forecast the inflation rate in each period. The remaining 5th player in each group is assigned the role of the government's "central bank". The central bank's objective is to set the interest rate in each period in such a way that he or she minimizes deviations of inflation from a certain benchmark (as discussed in detail below). The roles of the five players in each group will remain fixed over all periods of the experiment.

The timing of moves and the choices to be made each period

In each period, the private sector players move first. Each forms a forecast of the inflation rate for the period. Specifically, each private sector player is asked "What do you think inflation will be this period?" If you are a private sector player, you enter your forecast in the box on your computer screen and then click the OK button. Your forecast of inflation should be in percentage terms; if you think inflation will be X%, then enter X, where X is a real number. Your forecast can be any real number up to two decimal places. In choosing a forecast, each private sector player's objective is to accurately forecast the actual inflation rate for the period. Specifically, each private sector player's payoff in points is: $10 - (\text{My Inflation Forecast} - \text{Inflation})^2$, where "My Inflation Forecast" is the private sector player's own inflation forecast and the determination of the "Inflation" rate is explained below. After all four private sector players have submitted their forecasts for inflation, the average of these four inflation forecasts is calculated, and this is denoted as "Average Expected Inflation". The Inflation rate in each period is determined by the equation:

$$\text{Inflation} = \text{Average Expected Inflation} + .25 \times \text{Output Gap} \tag{20}$$

The first term, Average Expected Inflation is determined by the four private sector players. The "Output Gap" is the difference between actual and potential output (GDP). If actual output is above potential (if the Output Gap is positive), that raises inflationary pressure, while if output is below potential (if the Output Gap is negative) that reduces inflationary pressure. Notice however, that the weight on the Output Gap in determining Inflation is $1/4$ the weight on Average Expected Inflation in determining Inflation.

After Average Expected Inflation is determined, the central bank player learns the value of Average Expected Inflation and must choose the Interest Rate for the period. The central bank's choice of the Interest Rate directly affects the Output Gap via the equation:

$$\text{Output Gap} = 2 - 1 \times \text{Interest Rate} + E \tag{21}$$

In this equation, "E" is a mean zero demand shock that is a uniform random draw over the interval $[-1.25, 1.25]$. Notice that an Interest Rate greater than 2 leads to an expected negative Output Gap (since the expected value of E is 0) while an Interest Rate less than 2 leads to an expected positive Output Gap. Notice further that once the central bank has set the Interest Rate, then the Output Gap is determined via equation (2) and once the Output Gap is determined, then Inflation is also determined via equation (1). Prior to choosing the Interest Rate for the period, the central bank knows the following information for the period: Average Expected Inflation and the realization of the shock E. After viewing this information, the central bank is asked: "What interest rate do you want to choose this period?" If you are the central bank player, you enter your choice for the Interest Rate in the box on your computer screen and then click the OK button. Your interest rate choice should be in percentage terms; if you want to choose an interest rate of R% then enter R, where R is a real number. You can enter any real number up to two decimal places.

The central bank player's payoff function in points is: 20-(Inflation-2.5)^2. That is, the central bank player's payoff is highest when actual Inflation is exactly equal to a target value of 2.5. The central bank player must try to achieve this objective each period by its choice for the Interest Rate.

<u>Feedback</u>

At the end of each period, both types of players (private sector and central banks) will learn, or be reminded of: The Average Expected Inflation, the actual Inflation rate, the Output Gap, the central bank's choice of the Interest Rate and the actual realization of the shock E for the period. In addition, all players will learn their payoffs in points for the period. If the final period has not yet been played, the game will proceed to the next period, where the timing of moves and the choices to be made will be the same. However, in each period, there will be different random draws for the shock E.

Earnings

Your earnings are the sum of your payoff points from all periods played. A private sector player's maximum payoff is 10 points per period while a central banker's maximum payoff is 20 points per period.

Questions

Are there any questions before we begin?

SAMPLE HOMEWORK QUESTIONS

Model overview:

1. **Demand.** The demand for real goods and services is given by the following *IS* equation:

$$y = 2 - r + \epsilon, \tag{22}$$

   where y denotes the output gap, r denotes the real interest rate, and ϵ is an exogenous demand shock with a mean of zero. By assumption, the central bank can set r directly. All interest and inflation rates are expressed in percentages. That is, if the real interest rate is two percent, then $r = 2$.

2. **Supply.** The supply of goods and services is determined by the following *aggregate supply*

or *Phillips curve* equation:

$$\pi = \pi^e + 0.25y, \tag{23}$$

where π is the inflation rate and π^e is the private sector's expectation of the inflation rate. Note that there are no exogenous shocks to the supply equation.

3. **Monetary policy.** The central bank wishes to stabilize the inflation rate around a target value π^*. The central bank incurs a cost when the inflation rate is different from the target. The cost to the central bank is reflected in the following *loss function*:

$$L(\pi) = (\pi - \pi^*)^2 \tag{24}$$

Answer the following:

1. (a) Suppose that the central bank has an inflation target of $\pi^* = 2.5$. Compute the loss L to the central bank when the actual inflation rate is 0, 1, 2.5, and 3.

   (b) When $\pi^* = 2.5$, what is the value of π that minimizes the central bank's loss function given in equation (24)?

2. (a) Rewrite the aggregate supply equation (23) to express the output gap y as a function of π and π^e.

   (b) Use your answer to part (a) to eliminate y from the IS equation (22) and solve for the real interest rate r as a function of π, π^e, and ϵ.

   (c) Suppose that the public expects that the inflation rate will equal the central bank's target (i.e., $\pi^e = \pi^*$). Use the equation for the real interest rate that you derived in 2(b) to compute the appropriate real interest rate for each combination of π^*, π^e, and ϵ.

π^*	π^e	ϵ	r
2.5	2.5	0	
2.5	2.5	0.5	
2.5	2.5	1	
2.5	2.5	-0.5	
2.5	2.5	-1	

(d) Now, suppose that the public expects that the inflation rate will equal the central bank's target plus 1 percent. (i.e., $\pi^e = \pi^* + 1$). Use the equation for the real interest rate that you derived in 2(b) to compute the appropriate real interest rate for each combination of π^*, π^e, and ϵ.

π^*	π^e	ϵ	r
2.5	3.5	0	
2.5	3.5	0.5	
2.5	3.5	1	
2.5	3.5	-0.5	
2.5	3.5	-1	

(e) Compare your answers to part (d) with your answers to part (c). How does the increase in the expected inflation rate affect the appropriate value of the real interest rate?

TABLES

Table 1: Sample record sheets for P&P implementation.

(a) Record sheet for private sector players.

Private Sector Player Record Sheet ID Number: ______ Group Number: ______

Period No.	My Inflation Forecast	Average Inflation Forecast, π_t^e	Shocks ϵ_t	Shocks ω_t	CB Choice of r_t	Actual Output Gap, y_t	Actual Inflation Rate, π_t	My Points
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								

(b) Record sheet for central bank players.

Central Bank Player Record Sheet ID Number: ______ Group Number: ______

Period No.	Average Inflation Forecast, π_t^e	Shocks ϵ_t	Shocks ω_t	My Choice for r_t	Actual Output Gap, y_t	Actual Inflation Rate, π_t	My Points
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							

Table 2: Root mean square errors (RMSEs) of experimental data relative to selected benchmarks. Data are separated based on monetary policy regime and time period. Panel (a) reflects the performance of private sector groups. Panel (b) reflects central bank performance given private sector behavior. Panel (c) measures overall performance of the groups. All units are percentage points.

(a) Inflation forecast error: $\sqrt{\sum(\pi - \pi^e)^2}$.

	Dual Mandate	Inflation target
Periods 1–5	1.08	2.07
Periods 6–10	1.31	0.76

(b) Real interest rate relative to the optimal real interest rate given expected inflation: $\sqrt{\sum(r - r^{\text{OPT}})^2}$.

	Dual Mandate	Inflation target
Periods 1–5	3.48	6.23
Periods 6–10	3.86	3.06

(c) Actual relative to the rational expectations real interest rate: $\sqrt{\sum(r - r^{*})^2}$.

	Dual Mandate	Inflation target
Periods 1–5	4.34	8.27
Periods 6–10	5.25	3.04

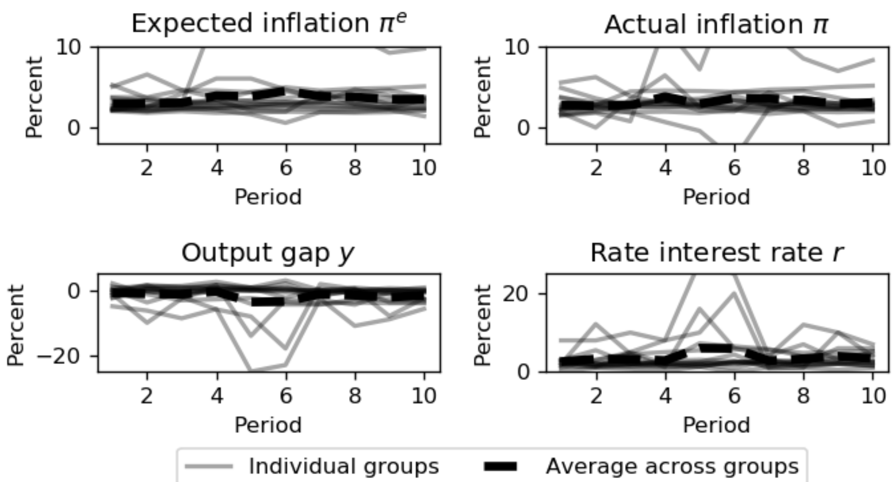
Table 3: Results from survey of participants from a spring 2018 intermediate macroeconomics course at UC, Irvine. 26 out of 65 participants responded.

Question	**Yes**	**No**
Did you enjoy the experiment?	96%	4%
Do you think that this experiment should be integrated into intermediate macroeconomics courses at UCI?	73%	27%
Do you think that this experiment would help UCI students better understand the IS-MP model of monetary policy and aggregate demand?	81%	19%

FIGURES

Figure 1: Outcomes for all groups divided by monetary policy regime. The thin solid lines depict values for individual groups while the dashed lines depict values for all groups in the policy regime.

(a) Dual mandate.



(b) Inflation targeting.

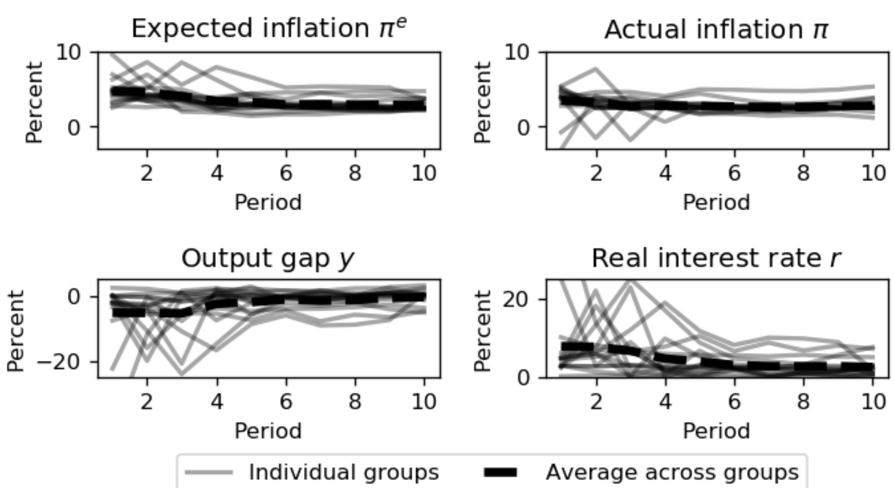


Figure 2: Outcomes for all groups divided by monetary policy regime. The solid lines depict average values for groups with a central bank facing a dual mandate while the dashed lines depict average values for groups with an inflation targeting central bank.

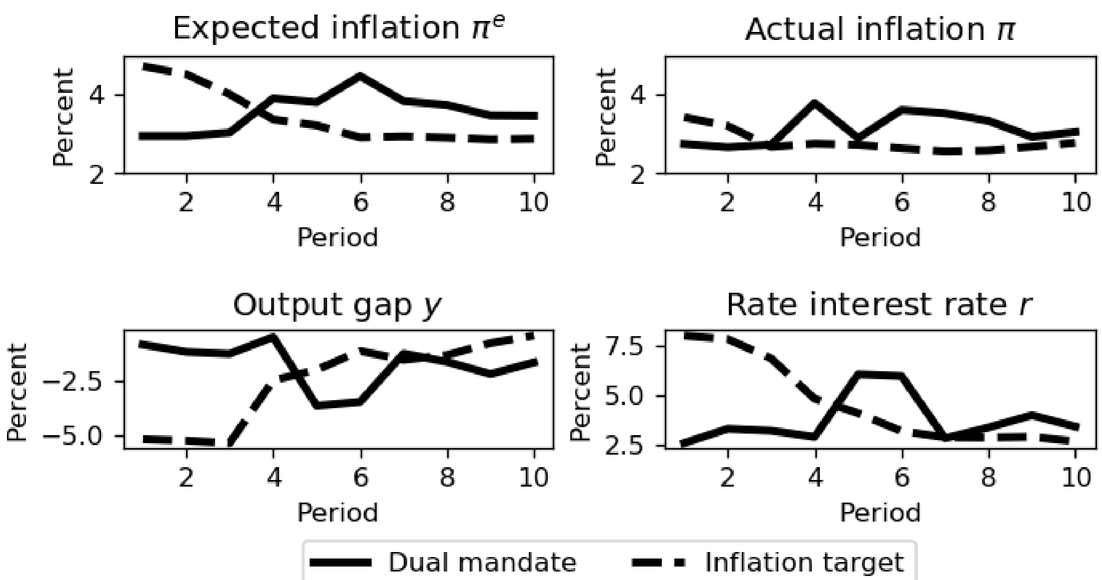


Figure 3: A group with a central bank with an inflation target that converged to the rational expectations equilibrium.

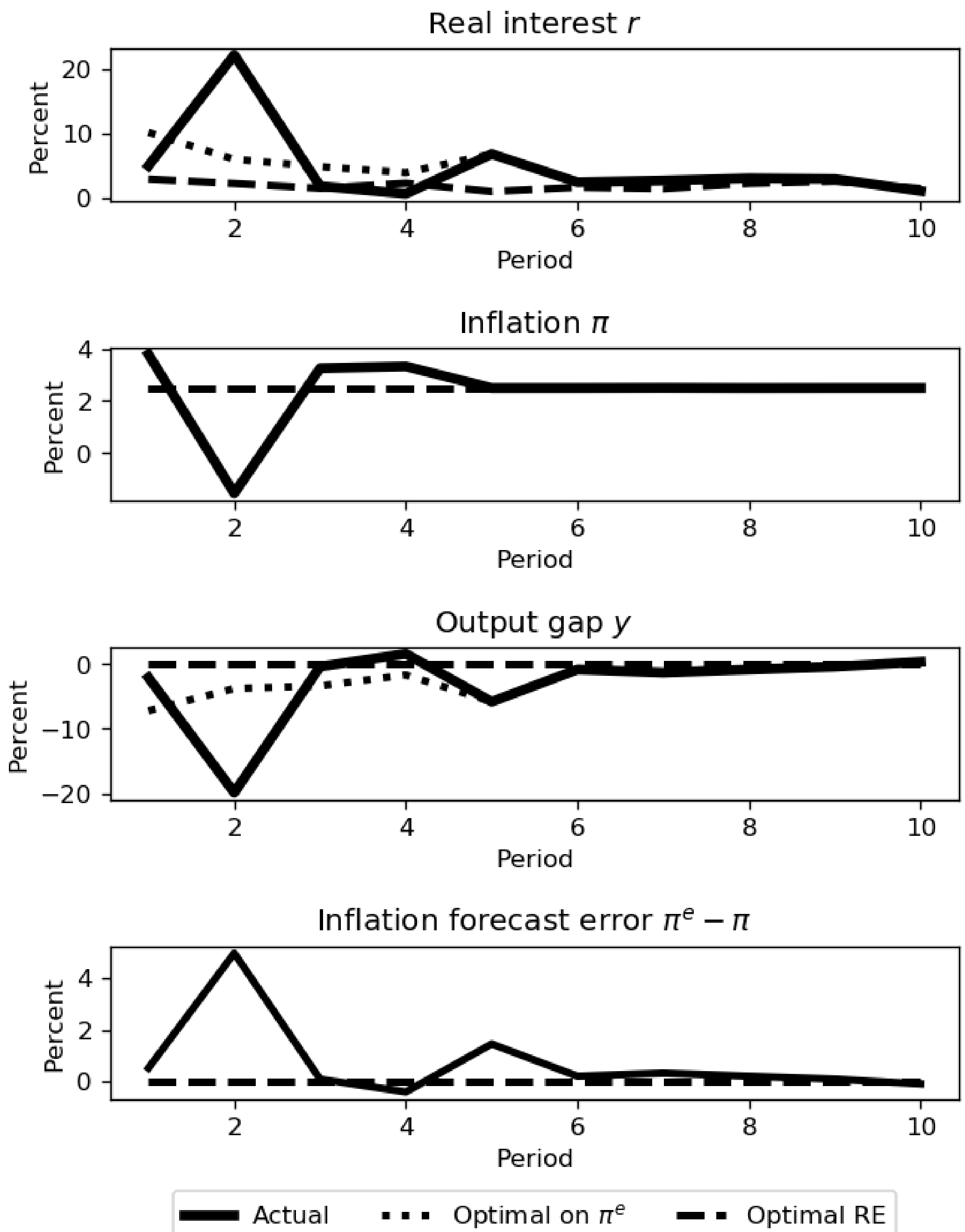


Figure 4: A group with a central bank with an inflation target that did not converge to the rational expectations equilibrium. The central bank converged to the optimal policy conditional on expected inflation while the private sector inflation forecast was consistently too high.

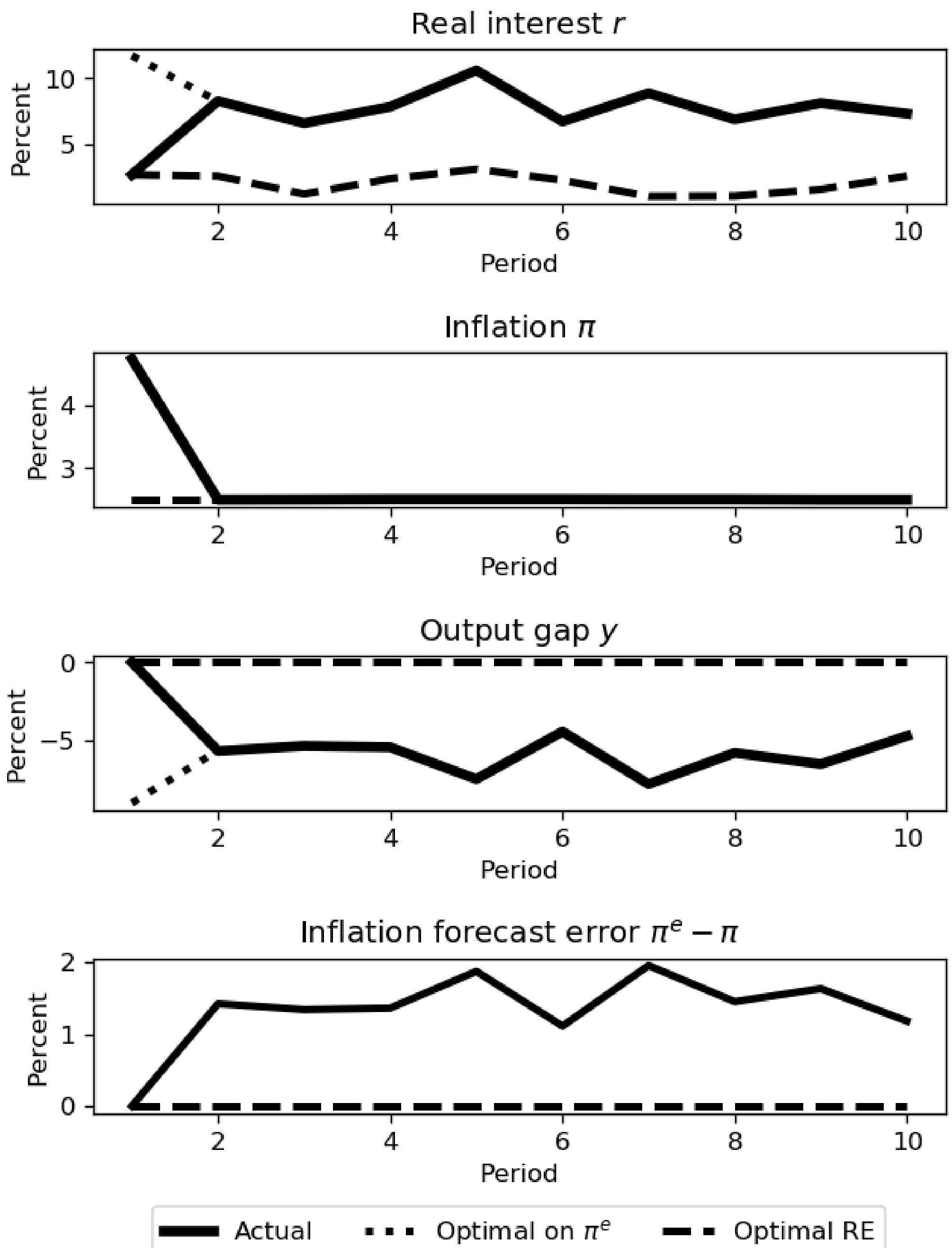


Figure 5: A group with a central bank with a dual mandate that was among the closest o the dual mandate groups to converging to the rational expectations equilibrium.

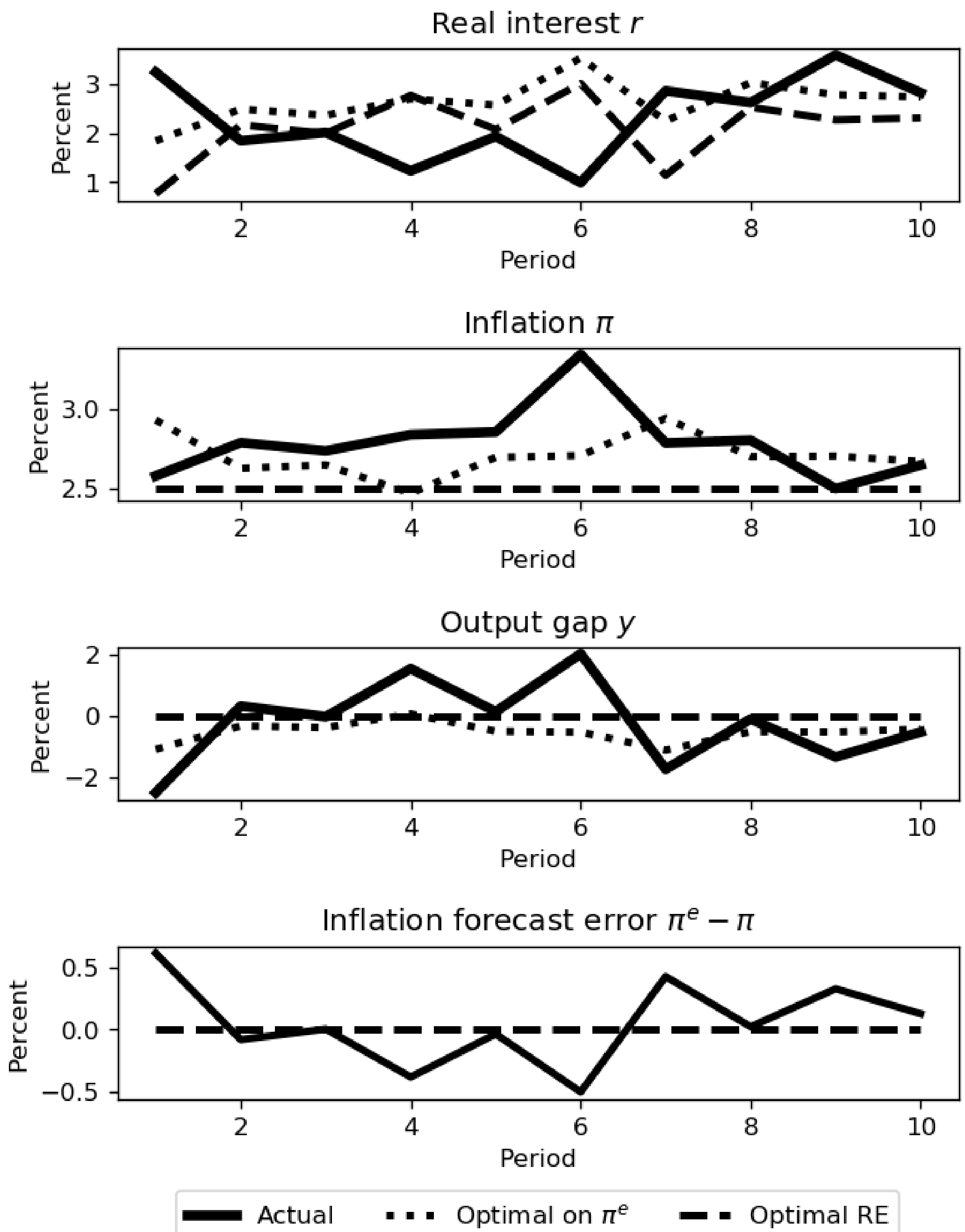


Figure 6: A group with a central bank with a dual mandate that did not converge to the rational expectations equilibrium. The central bank did not sufficiently tighten monetary policy to bring down inflation so the private sector's high inflation expectations became self-fulfilling.

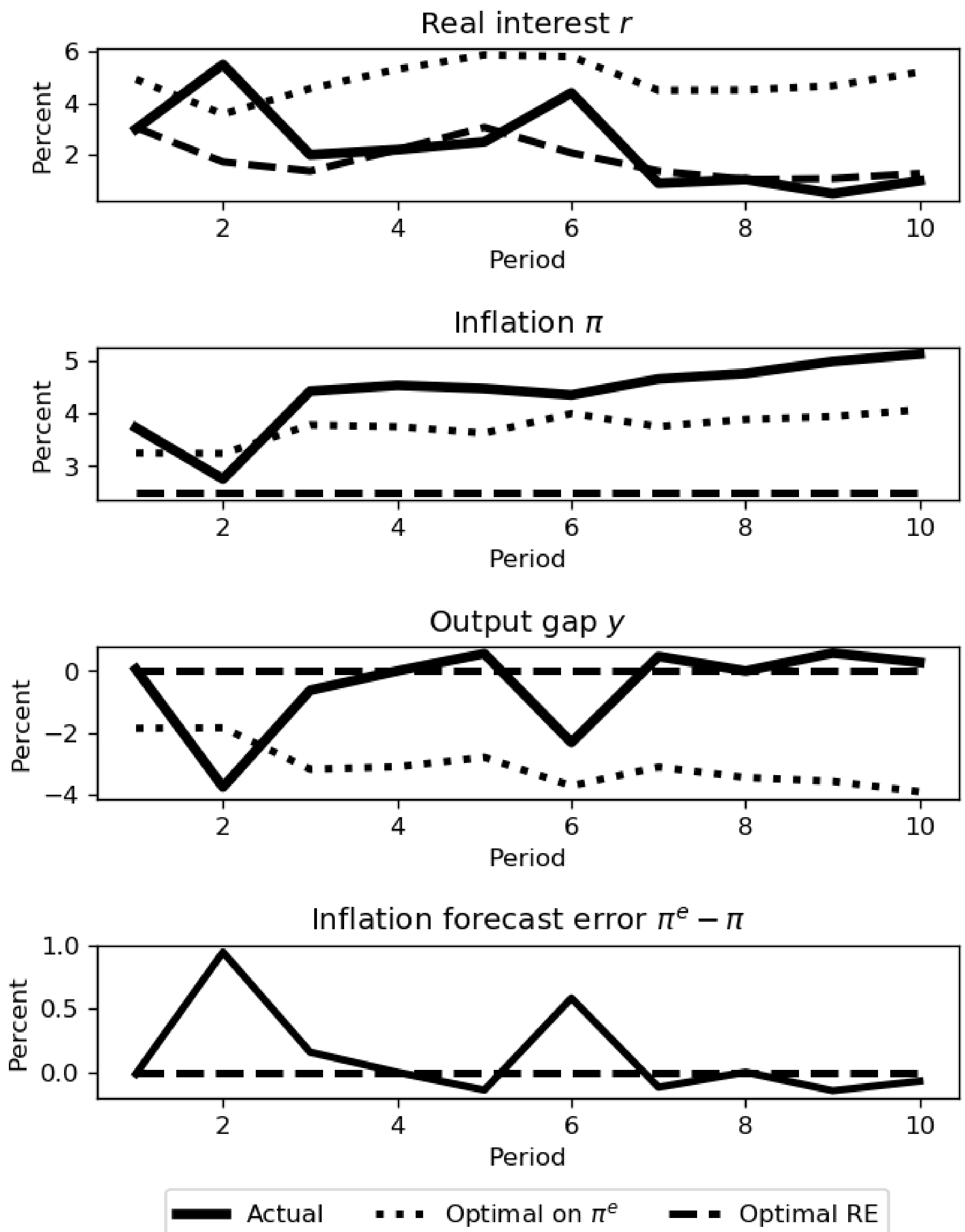


Figure 7: A group with a central bank with a dual mandate that did not converge to the rational expectations equilibrium. A large shock to expected inflation in period 5 drove the inflation rate up and the output gap down. The central bank did a reasonably good job responding to the expected inflation shock.

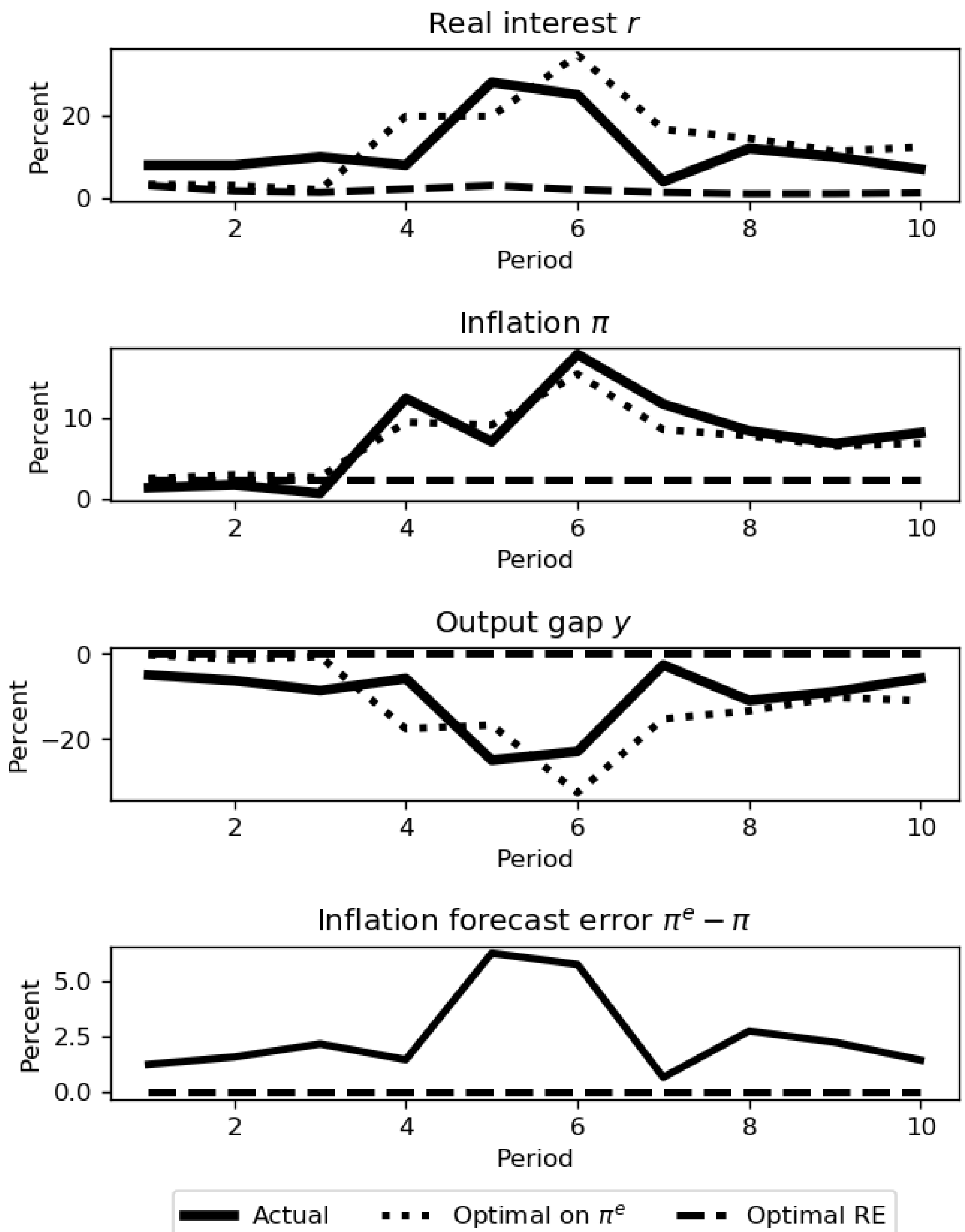


Figure 8: Monetary policy performance in each period using the *same loss function* to evaluate each policy regime: $(\pi - \pi^*)^2 + 0.1 \cdot y^2$. The solid lines depict average values for groups with a central bank facing a dual mandate while the dashed lines depict average values for groups with an inflation targeting central bank. The average loss for inflation targeting central banks fell sharply and remained close to 0 from period 6 on.

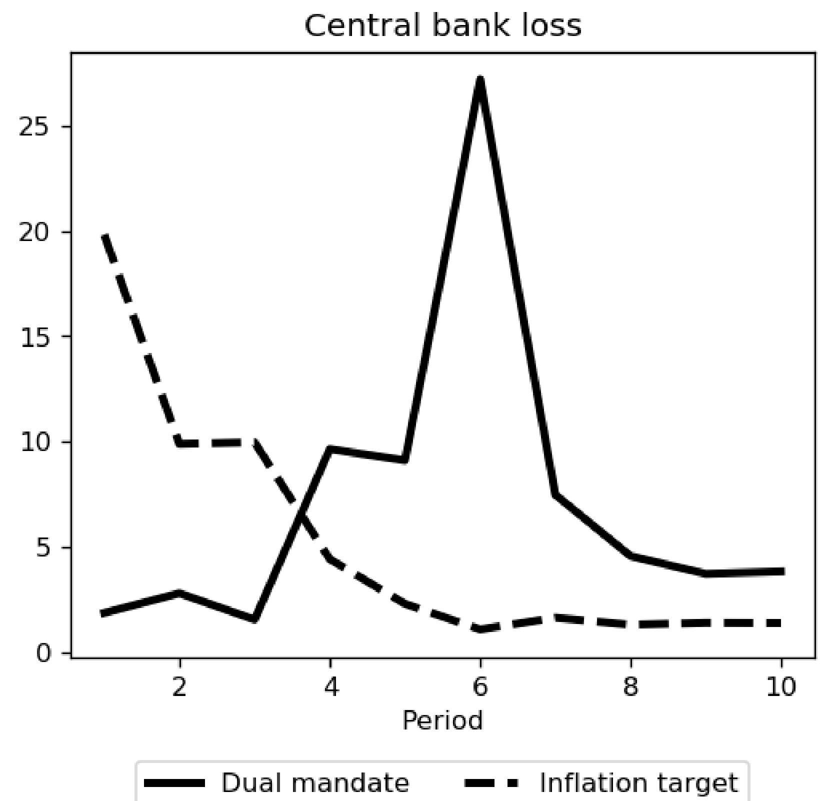


Figure 9: A suggestion for how to represent a group's results from the experiment for the purposes of an in-class discussion.

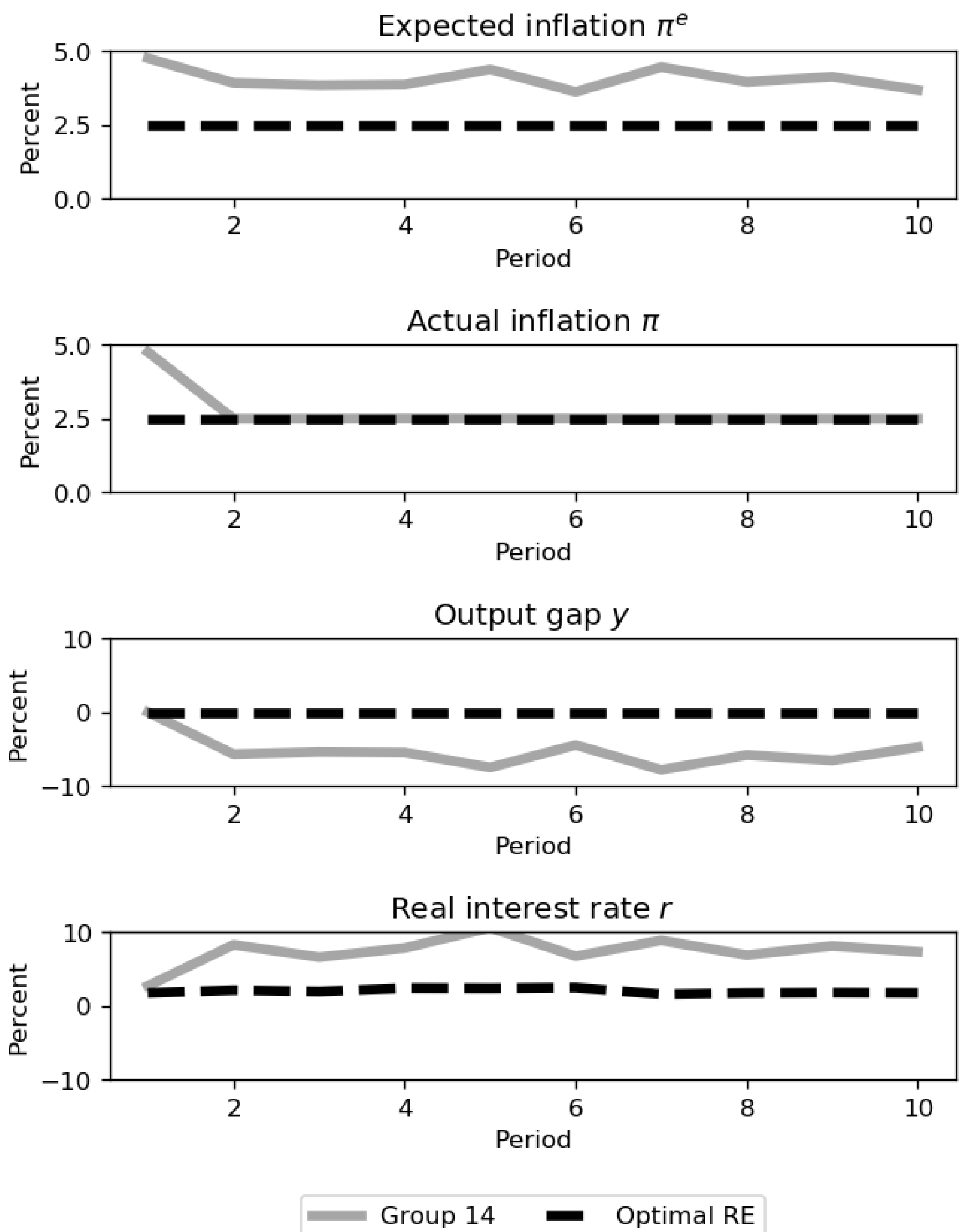


Figure 10: Central bank decision time by monetary policy regime. Left panel shows the cumulative densities of average central bank decision time for the first five periods. Right panel shows the cumulative densities the last five periods.

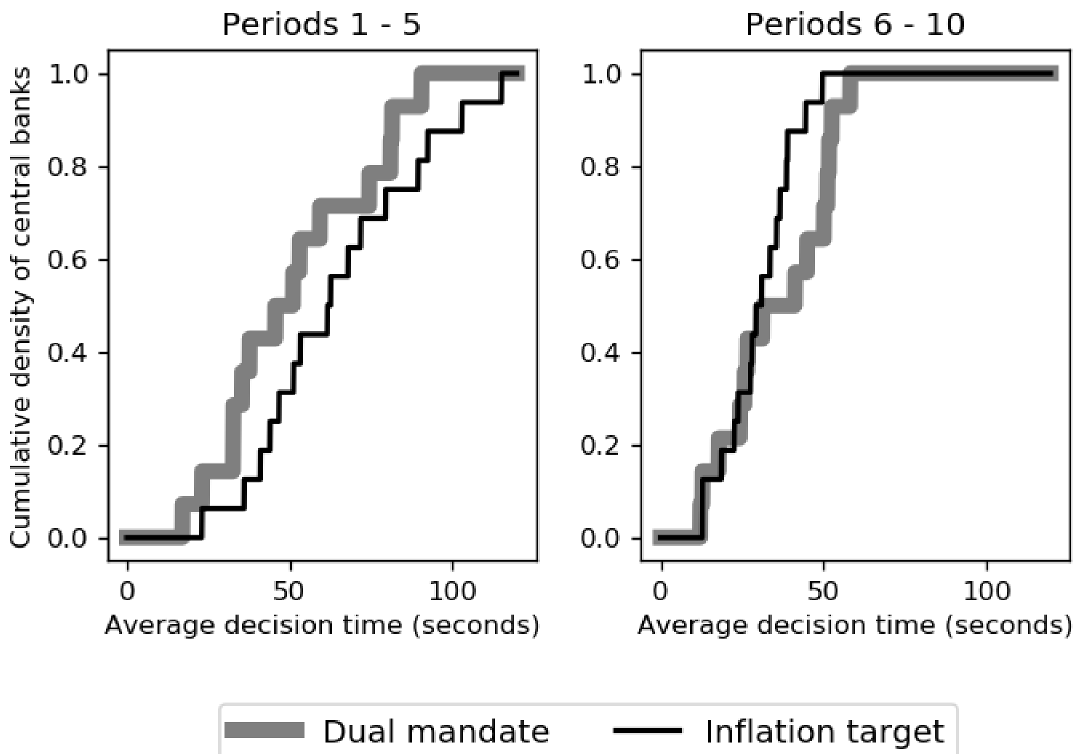


Figure 11: Inflation in inflation targeting groups facing normally-distributed shocks and uniformly-distributed shocks.

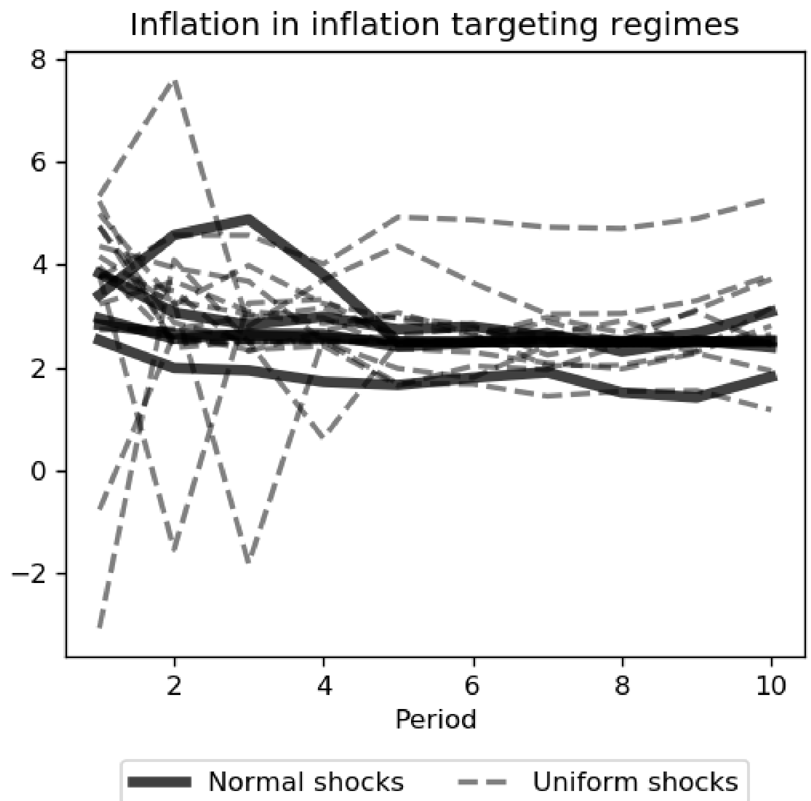


Figure 12: Inflation in groups with a central banker following a Taylor rule and facing a Phillips curve with lagged inflation.