

Monetary and Fiscal Policy Design at the Zero Lower Bound – Evidence from the Lab

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Abstract

The global economic crisis of 2007-8 pushed many advanced economies into a liquidity trap, a macroeconomic scenario characterised by nominal rates at the zero lower bound (ZLB), low inflation and output below trend. We design an experiment to generate empirical evidence on the effectiveness of policies aimed at managing expectations against liquidity traps in a controlled laboratory environment where expectations are elicited directly from human subjects. Our results suggest that monetary policy alone is not sufficient to insulate the economy from the risk of falling into a liquidity trap, even if it preventively cuts the interest rate when inflation threatens to fall below a certain threshold. However, such policy augmented with a fiscal switching rule succeeds in avoiding and escaping liquidity trap episodes. We also measure larger-than-unity fiscal multipliers when monetary policy is constrained by the ZLB. Experimental results in different treatments are well explained by adaptive learning.

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1 Introduction

The economic experiences in the aftermath of the 2007–8 global financial crisis have highlighted the issue of appropriate macroeconomic policy in deep recession. In reaction to a sharp fall of aggregate demand, the FED lowered its policy rate to 0.25% in December 2008. The Bank of England hit the lower bound on its short-term interest rate target of 0.5% in March 2009 and, as low inflation threatens recovery in the Euro area, the ECB cut the interest rate to 0.05% in September 2014 (see Fig. 1).

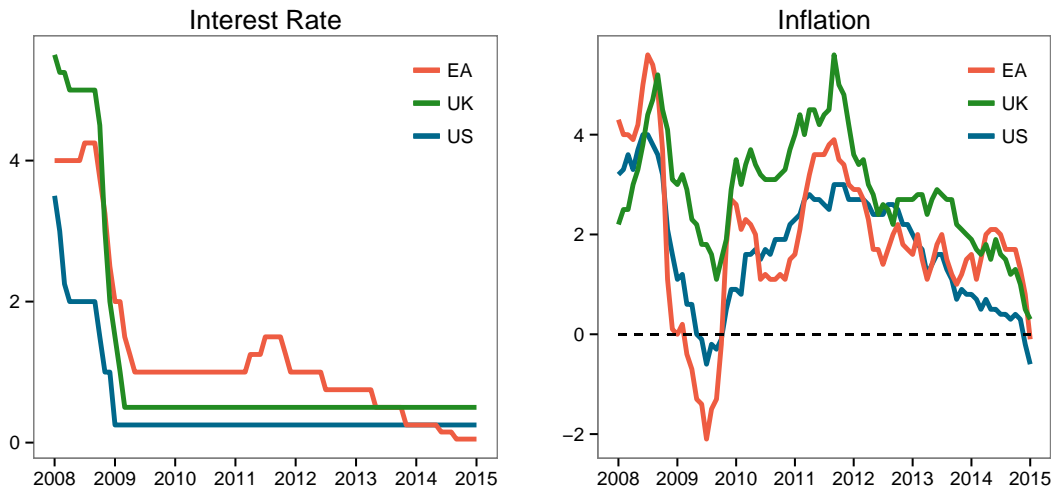


Figure 1: Macroeconomic scenarios in the Euro Area, US and UK.

This scenario characterised by depressed aggregate activity, low inflation and monetary policy unable to stimulate the economy due to policy rates set at, or close to, the zero lower bound (ZLB) is often referred to as *liquidity trap*. Recent research developments (see for example Benhabib et al. (2001a,b), Eggertsson and Woodford (2003), Werning (2012) and Mertens and Ravn (2014) among others) have described liquidity traps in models with rational expectations (RE) as low-inflation equilibria, additional to the targeted steady state, generated by “active” Taylor-type interest rate rules subject to a binding ZLB constraint. In models featuring multiple equilibria under RE, stability under learning has often been used as an equilibrium selection device (see Marcat and Sargent (1989) and Evans and

Honkapohja (2001) among others), based on the view that RE equilibria should be thought of as the long-run outcome of some learning and updating process (see, e.g., Lucas (1978, 1986), Sargent (1993), Grandmont (1998)).

Evans et al. (2008) and Benhabib et al. (2014) study the stability of the above mentioned multiple RE equilibria under adaptive learning finding that the targeted steady state is locally stable under learning while the low inflation equilibrium is unstable under learning. Therefore, large pessimistic shocks may push the economy away from the target and result in liquidity traps taking the form of deflationary spirals in which output and inflation decline over time.¹

In this paper we design a series of learning-to-forecast laboratory experiments (LtFEs) to empirically assess the plausibility of different outcomes of the aggregate dynamics in a New Keynesian model which presents multiple equilibria under RE. In particular, we test the predictions of a class of learning models in describing the emergence of liquidity traps as a result of adverse expectational shocks, and assess the effectiveness of monetary and fiscal policies targeted at avoiding and/or escaping the ensuing deflationary episodes.

In recent years laboratory experiments have become an increasingly important tool to address macroeconomic issues (see Duffy (2012) and the collection of papers in Duffy (2014) for a recent overview). LtFEs, a design first proposed by Marimon and Sunder (1993), are an ideal environment to study expectations' dynamics as the experimenter has full control over the model underlying the artificial economy, timing and magnitude of shocks, and information sets. LtFEs represent therefore an ideal test bed for policies aimed at managing expectations to prevent or escape liquidity traps. Recently, a number of LtFEs have been conducted within the context of linearised New Keynesian models to investigate inflation persistence Adam (2007), the appropriate design of Taylor rules Assenza et al. (2011); Pfajfar

¹Evans et al. (2008) use short-horizon learning based on Euler equations, while Benhabib et al. (2014) use infinite-horizon learning in which agents' decisions are based on forecasts over the entire future. Christiano and Eichenbaum (2012) and Mertens and Ravn (2014) also consider sunspot equilibria taking the form of a two-state Markov process, with the target outcome as an absorbing state.

and Zakelj (2015), disinflationary policies Cornand and M'Baye (2013) and the importance of expectational channel for macroeconomic stabilisation Kryvtsov and Petersen (2013); Pfajfar and Zakelj (2014); see also Assenza et al. (2014) for a survey of LtFEs in macroeconomics.

In our experiment subjects play the role of professional forecasters with the task of submitting forecasts for inflation and output. Forecasts are then aggregated and used as expectational input in the New Keynesian model describing the dynamics of inflation and output. By not making any a-priori assumption on expectations' dynamics but eliciting them directly from paid human subjects, we test the learnability of the targeted equilibrium and investigate the likelihood of adverse expectations dynamics triggered by pessimistic expectational shocks.

In this context, we study the effectiveness of monetary and fiscal policies aimed at insulating the laboratory economies from the risk of falling into liquidity traps. Following Evans et al. (2008), we consider policies that maintain the Taylor rule in “normal times”, but augment it by switching to aggressive monetary and fiscal policies if inflation falls below some thresholds.² In particular, we first consider an aggressive monetary policy in which the interest rate is preventively cut at the ZLB when inflation falls, or threatens to fall, below a certain threshold level. We then compare results with a treatment in which the aggressive monetary policy is augmented with a fiscal switching rule that raises public expenditures in order to prevent a fall in inflation below a certain threshold each time the cut in the interest rate is not enough to revert the decelerating inflation path. By comparing the two treatments, we ask whether an aggressive monetary policy is enough to prevent a fall into a liquidity trap. If not, we ask whether the addition of fiscal

²Recent literature has proposed other types of monetary and/or fiscal policies aimed at avoiding or escaping liquidity traps. Some authors proposed policies that make use of announcements and commitment to future policy actions (see, e.g., Krugman (1998), Woodford (2005) Eggertsson and Woodford (2003, 2004)) to control agents' expectations and avoid the effects of persistent deflationary outcomes. Other authors suggested fiscal or monetary policies leading to violations of the transversality conditions in order to rule out deflationary outcomes (see, e.g., Benhabib et al. (2002)). More recently, a significant strand of the literature analysed the effectiveness of standard fiscal policies when monetary policy is at the ZLB (see, e.g., Christiano et al. (2011), Woodford (2011), Eggertsson (2010) and Braun et al. (2012)).

policy measures can avoid deflationary outcomes.

Our findings can be summarised as follows. First, adaptive learning models are good predictors of the emergence of liquidity traps as a result of severely pessimistic expectations. As predicted by theoretical models under learning, when expected inflation (π^e) and expected net output (c^e) fall in a well-identified region of the (c^e, π^e) -space, the observed dynamics in the laboratory results in a self-reinforcing deflationary process in which inflation and output decline over time. The intuition for this result is that low enough expectations of future inflation and output imply low aggregate demand, due to high real interest rate values under a Taylor rule subject to the ZLB constraint. High real interest rates, combined with low expected output imply reduced levels of economic activity and lead to realisations of inflation below expectations. Expectations are thus revised further downward, pushing the economy deeper into the deflation trap. In this sense the initial fear of deflation becomes self-fulfilling.

Second, we find that liquidity traps in the form of deflationary spirals only arise in treatments that consider monetary policy alone, while they are never observed when monetary policy is augmented with the fiscal switching rule. The implementation of the fiscal switching rule leads to the disappearance of the low-inflation steady state and to a change in the expectational feedback of the model by interrupting downward trends in inflation and output, avoiding therefore coordination on destabilising trend-following forecasting behaviour.

Finally, we analyse the impact of fiscal policy at the ZLB and estimate larger-than-unity fiscal multipliers.

Recently, Arifovic and Petersen (2015) ran a parallel LtFE to study liquidity traps in laboratory economies. The experimental design of the two papers is similar in spirit, but differs in the following important dimensions. First, while Arifovic and Petersen (2015) use a linear approximation of the New Keynesian model to describe the experimental economies, we use the actual nonlinear specification consistent with the work of Evans et al. (2008), Mertens and Ravn (2014)

and Benhabib et al. (2014) among others. The rationale for this choice is that linearised models may provide poor approximation of inflation and output dynamics in the presence of large deviations from steady state, as in the case of liquidity trap episodes.³ Second, Arifovic and Petersen (2015) impose large negative shocks to aggregate demand to generate a liquidity trap environment. In contrast, we use only small IID shocks to our experimental economies. The reason for this choice is that we are interested in testing the predictions of learning models describing the emergence of liquidity traps as a result of *shifts in expectations* which produce sufficient deflationary pressures to cause the ZLB to bind. By having only small IID shocks affecting actual realisations of inflation and output, the risk of falling in a liquidity trap arises only from adverse *expectational* shocks.⁴ Moreover, the noise term in Arifovic and Petersen (2015) follows a correlated AR(1) process. In such an experimental environment it is not clear whether fluctuations in inflation and output are expectations driven or solely driven by exogenous shocks. On the other hand, in our experimental economies with only small IID shocks, any observed large fluctuations in aggregate variables must be endogenously driven by expectations. Third, Arifovic and Petersen (2015) focus on the role of communication strategies of central banks near the ZLB while we test the effectiveness of aggressive monetary policy and fiscal switching rules.

The paper is organised as follows. Section 2 describes the theoretical framework underlying the experimental economies. Section 3 provides details on the design of the experiment. Section 4 presents the experimental outcomes while Section 5 further discusses the results and contributes to a recent policy debate about a possible increase in the FED target rates. Finally Section 6 concludes.

³The dangers of relying on linear approximations to study liquidity trap dynamics are documented, for example, in Judd et al. (2012), Fernandez-Villaverde et al. (2012), Braun et al. (2012) and Aruoba et al. (2013).

⁴Mertens and Ravn (2014) point out that the impact of exit strategies from liquidity trap episodes depends on whether the liquidity trap is caused by non-fundamental expectational shocks or by fundamental shocks. Aruoba et al. (2013) estimate a model with fundamental and non-fundamental shocks. Using data from Japan they find that the country experienced the fall to a deflation regime in 1999 due to adverse non-fundamental confidence shocks. Finally, Schmitt-Grohé and Uribe (2013) emphasise the role of expectational shocks to explain the joint occurrence of liquidity traps with jobless growth recovery.

2 Theoretical Framework

2.1 A Non-linear New Keynesian Model

The experimental economy is based on a standard New Keynesian (NK) framework with a private sector producing differentiated output under monopolistic competition and price frictions. In order to study exact global dynamics in regions of the state space which are far from the targeted steady state, as in the case of liquidity trap episodes, we follow Evans et al. (2008), Braun et al. (2012) and Benhabib et al. (2014) among others, and interpret price frictions as stemming from adjustment costs *à la* Rotemberg (1982). This price-setting environment allows us to use the actual nonlinear NK model specification without introducing additional endogenous state variables, while delivering the same functional form for the linearised model around the targeted steady state as in the often used pricing model *à la* Calvo (1983).⁵

The key equations describing aggregate dynamics (see Evans et al. (2008) and Appendix B for details) are given by

$$c_t = c_{t+1}^e \left(\frac{\pi_{t+1}^e}{\beta R_t} \right)^{1/\sigma} \quad (1)$$

$$\pi_t(\pi_t - 1) = \beta \pi_{t+1}^e (\pi_{t+1}^e - 1) + \frac{v}{\alpha \gamma} (c_t + g_t)^{\frac{1+\epsilon}{\alpha}} + \frac{1-v}{\gamma} (c_t + g_t) c_t^{-\sigma}. \quad (2)$$

Eq. (1) describing the dynamics of net output c_t (i.e., output minus government spending of the aggregate good) is a standard Euler equation, where c_{t+1}^e and π_{t+1}^e denote respectively expectations of future net output and inflation, R_t is the nominal interest rate set by the central bank, $0 < \beta < 1$ is the discount factor and $\sigma > 0$ refers to the intertemporal elasticity of substitution.

Eq. (2) is a New Keynesian Phillips Curve describing the dynamics of inflation π_t , where g_t is government spending of the aggregate good, $\epsilon > 0$ refers to the marginal disutility of labour, $0 < \alpha < 1$ is the return to labor in the production

⁵See Christiano and Eichenbaum (2012) for details.

function, $\gamma > 0$ is the cost of deviating from the inflation target under Rotemberg price adjustment costs, and $\nu > 1$ is the elasticity of substitution between differentiated goods. The term $\pi_t(\pi_t - 1)$ in Eq. (2) arises from the quadratic form of the adjustment costs. Let $\pi_t(\pi_t - 1) = Q_t$. The appropriate root for given Q is $\pi \geq 1/2$ and so we need to impose $Q \geq -1/4$ to have a meaningful model.

For the experimental implementation of the economy described by Eqs. (1)–(2) we follow the parameters’ calibration of Benhabib et al. (2014). The time discount rate is set to $\beta = 0.99$, the labour share is set to $\alpha = 0.7$, and parameter ν is set to 21. The parameter γ , measuring the cost of deviating from the inflation target under Rotemberg pricing, is related to the price rigidity parameter of Calvo pricing, denoted by ϕ , according to $\gamma = \frac{(\nu-1)\phi}{(1-\phi)(1-\beta\phi)}$. Following Benhabib et al. (2014), we consider a Calvo pricing parameter ϕ of approximately 0.8, corresponding to $\gamma = 350$ under their calibration. Preferences are assumed to be logarithmic so that $\sigma = \epsilon = 1$.

2.2 Monetary and Fiscal Policy

Following Evans et al. (2008), we consider an *aggressive* monetary policy of the form

$$R_t = \begin{cases} 1 + (R^* - 1) \left(\frac{\pi_{t+1}^e}{\pi^*} \right)^{\frac{AR^*}{R^*-1}} \left(\frac{c_{t+1}^e}{c^*} \right)^{\frac{\phi_y R^*}{R^*-1}} & \text{if } \pi_t \geq \tilde{\pi} \\ \tilde{R} & \text{if } \pi_t < \tilde{\pi} \end{cases}, \quad (3)$$

where $\tilde{R} = 1.0001$ corresponds to the ZLB on the nominal interest rate.⁶ The monetary policy rule (3) is defined as aggressive since, while in “normal” times ($\pi_t \geq \tilde{\pi}$) it follows a standard forward-looking Taylor rule, it preventively cuts the nominal interest rate to the ZLB each time inflation drops below a given threshold $\tilde{\pi}$.⁷ We set the reaction coefficients in the interest rate rule to $\phi_\pi = 2$ and $\phi_y =$

⁶We set \tilde{R} so that the corresponding interest rate $\tilde{R} - 1$ is small but positive in order to keep money demand finite, see Appendix B for details.

⁷The main results below would also hold in the case of a contemporaneous Taylor rule as emphasised by Evans et al. (2008). Using a forward-looking specification for the Taylor rule

0.5, which are in line with empirical estimates, see, e.g., Taylor (1999), Judd and Rudebusch (1998), Clarida et al. (2000) and Orphanides (2003) among others. This parameterisation ensures local determinacy of the targeted steady state (π^*, c^*) under RE. However, as emphasised by Benhabib et al. (2001b), “active” Taylor rules imply the existence of a second low-inflation steady state (π_L, c_L) , which is locally indeterminate under RE. Given our parameterisation, there are no steady states other than the target steady state (π^*, c^*) and the low-inflation steady state (π_L, c_L) .

Fiscal policy is specified as

$$g_t = \bar{g}, \tag{4}$$

where \bar{g} is fixed. As in Evans et al. (2008), we set $\pi^* = 1.05$ which implies a net output steady state value of $c^* = 0.7454$.⁸ Under the aggressive monetary policy in Eq. (3) the low-inflation steady state is given by $(\pi_L, c_L) = (0.99, 0.7428)$. The two equilibria of the model are depicted in Fig. 2a. The low inflation steady state (π_L, c_L) is denoted by a (blue) “L”, while the targeted steady state π^*, c^* is denoted by a (green) “T”.

We also consider the fiscal policy design proposed by Evans et al. (2008) to prevent liquidity traps and deflationary spirals. The *fiscal switching rule* prescribes an increase in public expenditures g_t each time monetary policy fails to achieve $\pi_t > \tilde{\pi}$. Evans et al. (2008) show that in model (1)–(2), given expectations π_{t+1}^e and c_{t+1}^e , any level of inflation π_t can be achieved by setting g_t sufficiently high.⁹ Therefore the fiscal switching rule is specified as follows: if the inflation threshold

facilitates the experimental implementation due to the nonlinear nature of the model.

⁸We chose an inflation target of 1.05 to clearly separate the low inflation and targeted steady states in the experimental economies. Qualitative results are robust to alternative target values.

⁹Moreover, Evans et al. (2008) show that any level of inflation π_t (above 0.5) corresponds to a unique value of g_t through Eq. (2).

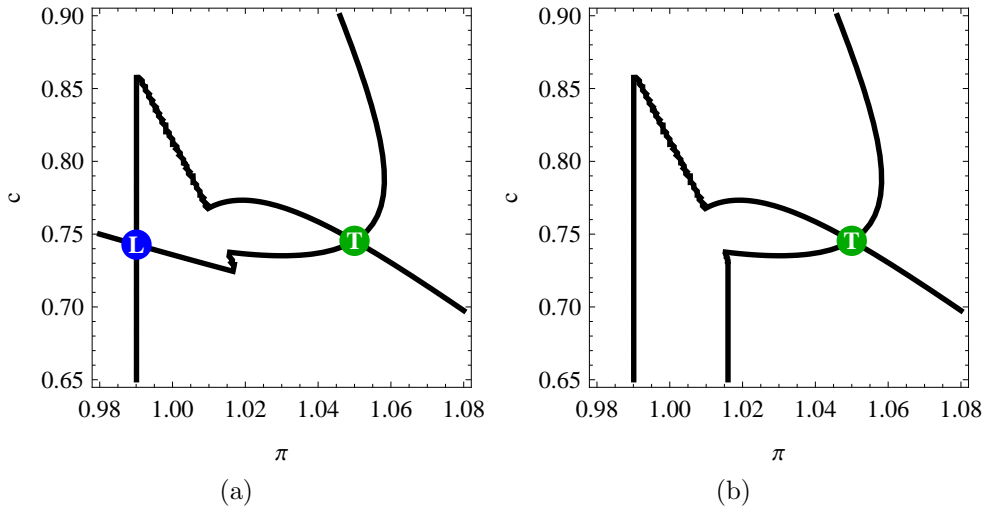


Figure 2: **Panel (a)**: Multiple equilibria with coexistence of low inflation steady state L and targeted steady state T under aggressive monetary policy. **Panel (b)**: Unique equilibrium, i.e. targeted steady state T under combined monetary policy and fiscal switching rule.

$\tilde{\pi}$ is not achieved under the aggressive monetary policy in Eq. (3), then we

$$\left\{ \begin{array}{l} \text{(i) compute the interest rate } \hat{R}_t \text{ consistent with Eqs. (1)–(2) and } \pi_t = \tilde{\pi} \\ \text{(ii) set } R_t = \max[\hat{R}_t, \tilde{R}] \\ \text{(iii) if } R_t = \tilde{R} > \hat{R}_t, \text{ then } g_t \text{ is adjusted upward such that } \pi_t = \tilde{\pi} (+\epsilon), \end{array} \right. \quad (5)$$

where ϵ is a small tolerance parameter set to 0.001. As shown by Evans et al. (2008), setting $\pi_L < \tilde{\pi} < \pi^*$ ensures the uniqueness of the targeted steady state. In our experimental design we set $\tilde{\pi} = 1.016$, which is above the low-inflation steady state but low enough considering the 1.05 inflation target. The unique equilibrium of the system under combined monetary (Eq. (3)) and fiscal policy (Eq. (5)) is illustrated in Fig. 2b.

The idea behind the monetary-fiscal policy mix is the following. If the inflation target is not achieved under a standard Taylor rule, monetary policy is relaxed in order to stimulate the economy. If the ZLB constraints the effectiveness of monetary policy, aggressive fiscal policy is activated.

In our setting fiscal policy takes the form of changes in government spending.

A temporary increase in government expenditures leads to a temporary debt build-up, as variations in g_t are not balanced by equal changes in lump sum taxes (see specification of fiscal policy in Appendix B and Evans et al. (2008) for further details). Government spending is then gradually reduced as expectations of inflation and net output recover. On a recovery path converging to the target, debt gradually returns to steady state and interest rate returns to normal levels.

2.3 Learning, E-Stability and Equilibrium Selection

In this subsection, we summarize the non-linear NK model dynamics under adaptive learning, described in detail in Evans et al. (2008). In Section 4, we then evaluate whether adaptive learning explains the observed dynamics in the laboratory experiments.

In the presence of multiple equilibria and uncertain impact of policy changes, it has been argued that equilibria that yield unstable dynamics under learning should be dismissed.¹⁰ A commonly used criterion for equilibrium selection is the expectational stability, or E-stability, under adaptive learning, which is closely related to dynamic stability under simple recursive learning schemes, such as least squares or constant gain learning (Marcet and Sargent (1989), Evans and Honkapohja (2001)). Rational expectations and adaptive learning can thus be viewed as complementary approaches: rational expectations allows one to identify the steady states, cycles, or other patterns that might be collectively learnable in the long run, and adaptive learning allows one to test their stability and learnability.

We write the temporary equilibrium map for c_t and π_t implicitly defined by Eqs. (1) and (2), together with policy equations (3)–(5), and given expectations

¹⁰See, e.g., McCallum (2003), Adam (2003), Lettau and Van Zandt (2003) among others, and Christiano and Eichenbaum (2012) for an application to liquidity trap contexts.

c_{t+1}^e and π_{t+1}^e , as follows:

$$\pi_t = F_\pi(\pi_{t+1}^e, c_{t+1}^e) \quad (6)$$

$$c_t = F_c(\pi_{t+1}^e, c_{t+1}^e). \quad (7)$$

Following Evans et al. (2008), Mertens and Ravn (2014) and Benhabib et al. (2014), we consider steady state learning, where expectations are given by

$$\pi_{t+1}^e = \pi_t^e + \delta_t(\pi_{t-1} - \pi_t^e) \quad (8)$$

$$c_{t+1}^e = c_t^e + \delta_t(c_{t-1} - c_t^e) \quad (9)$$

The term δ_t refers to the gain-sequence. Under least-squares learning the gain-sequence is usually set as $\delta_t = t^{-1}$ (decreasing gain), whereas under constant gain learning it is set to $\delta_t = \delta$, where $0 < \delta < 1$ is a small positive constant; notice that the limit case $\delta = 1$ corresponds to naive expectations. The theoretical results for the model under learning are based on E-stability analysis under the learning rules (8)–(9). An equilibrium is said to be stable (unstable) under learning if it is stable (unstable) under these learning rules with decreasing gain. When an equilibrium is E-stable under constant gain learning, there is local convergence of learning in a weaker sense to a random variable that is centered near the equilibrium.¹¹ Rules (8)–(9) are the Perceived Law of Motions (PLMs) consistent with the minimum state variable (MSV) solutions of our simple experimental economy setup. Equilibria whose expectations can be acquired via simple learning rules, such as Eqs. (8)–(9), are widely believed to constitute more plausible model predictions than equilibria that would require more sophisticated coordination devices.

An important goal of the paper is to test experimentally whether adaptive learning models are good predictors of the emergence of liquidity traps when expectations are provided directly by human subjects.

E-stability of the rational expectation equilibrium (REE) is determined by the

¹¹See Evans and Honkapohja (2001) for a formal treatment.

Jacobian matrix of the so-called T-map, i.e. the mapping from the PLM to the corresponding Actual Law of Motion (ALM), evaluated at the steady state (see Evans and Honkapohja (2001) for details). Formally, the REE is said to be E-stable if the differential equation (in notional time τ)

$$\begin{pmatrix} d\pi^e/d\tau \\ dc^e/d\tau \end{pmatrix} = \begin{pmatrix} T_\pi(\pi^e, c^e) \\ T_c(\pi^e, c^e) \end{pmatrix} - \begin{pmatrix} \pi^e \\ c^e \end{pmatrix} \quad (10)$$

is locally asymptotically stable at a steady state (π, c) , where $T(\cdot)$ is the T-map defined as (see Evans et al. (2008, p. 1445)):

$$T_\pi(\pi^e, c^e) = EF_\pi(\pi_{t+1}^e, c_{t+1}^e) \quad (11)$$

$$T_c(\pi^e, c^e) = EF_c(\pi_{t+1}^e, c_{t+1}^e). \quad (12)$$

The T-map gives the actual means for π_t and c_t when agents have expectations π_{t+1}^e and c_{t+1}^e . For the E-stability condition to be satisfied, both eigenvalues of the Jacobian matrix must have negative real parts. Evans et al. (2008) show that under the aggressive monetary policy regime of Eq. (3) and the constant fiscal policy rule of Eq. (4), the targeted steady state (π^*, c^*) is locally stable under learning, while the low-inflation steady state (π_L, c_L) is locally unstable under learning, taking the form of a saddle point. In fact, given the parameterisation of our experimental economy, the eigenvalues computed at the low-inflation steady state are real and of different signs, while for the targeted steady state we have complex eigenvalues with negative real parts.¹²

The phase diagram of the dynamics under learning is given in Fig. 3. The solid black and the dashed black curves depict respectively the stable and unstable manifold of the saddle low-inflation equilibrium (blue “L”). The stable and unstable manifolds have been obtained as numerical approximations of learning dynamics converging to the low-inflation steady state (π_L, c_L) respectively in forward and

¹²The real eigenvalues at the low inflation steady state are $(0.52, -0.35)$, while the complex eigenvalues at the targeted steady state are $(-0.33 + 0.22i, -0.33 - 0.22i)$.

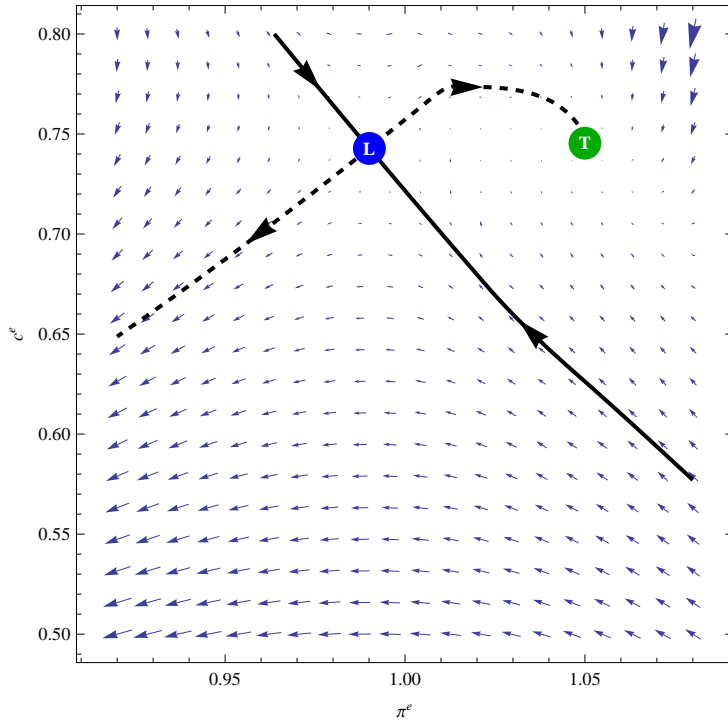


Figure 3: Learning dynamics under aggressive monetary policy and constant fiscal policy.

backward time. The E-stability analysis shows that although the targeted steady state is locally stable under learning, the saddle property of the low-inflation steady state creates a region in the phase space in which inflation and output decline over time. In particular, the stable manifold of the low inflation steady state divides the phase space in two regions: the *stable* region above the manifold, characterised by convergence to the targeted steady state (π^*, c^*) , and the *unstable* region below the manifold characterised by deflationary dynamics. This analysis shows that adverse expectational shocks may cause liquidity traps taking the form of deflationary spirals. Large pessimistic shocks may in fact push expectations into the unstable region below the stable manifold of the low inflation steady state, leading to a self-reinforcing process in which inflation and output decline over time. On the other hand, when the aggressive monetary policy is augmented with the fiscal switching rule described in Eq. (5), the targeted steady state is globally stable under learning, as discussed in Evans et al. (2008).

In the experiment we are interested in empirically testing these predictions of

the learning model in describing the occurrence of liquidity traps.

3 Experimental Design

The experiment is a LtFE with a group design and within session randomisation. At the start, all participants are divided into groups (experimental economies) of six. Subjects only interact with people in their experimental economy. The only task for subjects is to make two-period-ahead forecasts of inflation and net output for 50 periods. Average forecasts are then used as input to model (1)–(3), with fiscal policy defined by either (4) or (5) (see below for a description of treatments), in order to compute realisations of inflation and net output.

In each period t , when making forecasts for period $t + 1$, the information set visualised on subjects' screens includes all realisations of inflation, net output, interest rate and government expenditures up to period $t - 1$, their own forecasts of inflation and net output up to period t , and their scores reporting how close their past forecasts were to realised values up to period $t - 1$. Fig. 16 in Appendix D shows the computer interface as visualised by participants in the experiment.

Subjects' payments depend on their forecasting performance. At the end of the experiment it is randomly determined for each participant whether she is paid for inflation forecasting or net output forecasting. The total score for inflation or net output forecasting is the sum of the respective forecasting score over all periods. The score of subject i in each period for e.g., inflation forecast is determined as $100/(1 + |\pi_{i,t}^e - \pi_t|)$, where $\pi_{i,t}^e$ denotes subject i 's forecast for period t and π_t is the realised value of inflation in period t (the score is computed in an analogous way for net output). Therefore subjects' payment decrease with the (absolute) distance of realisations from their forecasts.¹³

In the instructions, subjects receive a qualitative description of the economy, explaining the mechanisms governing the model equations, but they do not re-

¹³See also Adam (2007), Assenza et al. (2011) and Pfajfar and Zakelj (2015) who use an analogous payoff function.

ceive quantitative information on the exact equations or values of the structural parameters of the economy. Subjects are informed, e.g. that there is a positive relation between realised net output and inflation and output predictions, and a negative relation with the interest rate. This qualitative information design is a standard strategy in LtFE aiming at testing the learnability of RE equilibria (see Duffy (2012) and Hommes (2011)). In order to prevent perfect coordination of subjects on the deterministic steady states, we buffet the economy with small additive white noise shocks to Eqs. (1)–(2) with a standard deviation of 0.0025. Subjects are informed that realisations inflation and net output are affected by these small random shocks. The complete instructions can be found in Appendix C.

As noticed in Section 2, the model underlying the experimental economies is well defined if condition $Q \geq -1/4$ is satisfied. Therefore we impose $\pi^e \in [0.8, 1.2]$ and $c^e \in [0.35, 0.9]$. Given the calibration of the experimental economy described in Section 2, these restrictions ensure that condition $Q \geq -1/4$ is satisfied throughout the experiment. In the experiment the restrictions were implemented as a message popping up in the subjects' screen in case their forecasts were outside the allowed range.¹⁴

Finally, in order to keep the experimental setup as simple as possible for subjects, we did not introduce the concept of gross inflation which might be confusing and harder to explain. Instead, we elicited forecasts in percentage points and translated them to gross inflation as input to the model. For the same reason, we elicited values of net output forecasts scaled up by a factor of 100 and translated them to the appropriate format as input to the model.

¹⁴During the experiment these constraints were never binding, aside from the cases of liquidity traps in the form of deflationary spirals. In these cases the inflation rate fell below -20% and output dropped to levels lower than 50% of the equilibrium value. This scenario was enough for us to show the occurrence of liquidity traps in the form of deflationary spirals. Wild oscillations following the periods in which subjects reached the minimum value they were allowed to submit as forecasts are not meaningful from an economic point of view.

3.1 Treatments and Hypotheses

We implement a 2×2 experimental design with 4 treatments which differ in the following dimensions. First, we consider two policy regimes (*Policy* dimension): a policy regime, labeled M, which is characterised by aggressive monetary policy (Eq. (3)) and a fixed amount of public expenditures (Eq. (4)); a second policy regime, labeled F, which is characterised by the same aggressive monetary policy augmented with the fiscal switching rule (Eq. (5)). The second dimension concerns initialisation and timing of adverse expectations dynamics causing the ZLB to bind (*Expectations* dimension). In one scenario, labeled as P, below-target expectations are induced at the beginning of the experiment in the form of initial severe pessimism (see below for details). In the other scenario, labeled as S, pessimistic expectational shocks are induced later in the experiment, i.e., when the experimental economies are already moving along a converging path and are in the proximity of the target equilibrium (see below for details). The 2×2 matrix describing the 4 treatments implemented in the experiment is reported in Table 1.

Policy	Expectations	
	Severe Pessimism (P)	Expectational Shock (S)
Aggressive Monetary only (M)	MP	MS
Additional Fiscal Rule (F)	FP	FS

Table 1: Four treatments' summary

Within the context of the first policy regime labeled as “Aggressive Monetary” (M) in Table 1, we are interested in testing the predictions of adaptive learning models about the occurrence and characteristics of liquidity trap episodes, summarised in the following proposition:

Proposition 1. *Under the policy regime M (described by Eqs. (3)–(4)), pessimistic expectations falling in the “unstable” region described by the area in the (π^e, c^e) -space below the stable manifold, caused by either initial severe pessimism (treatment MP) or by adverse expectational shocks (treatment MS), lead to the emergence of liquidity traps in the form of deflationary spirals.*

In order to study situations in which, due to adverse expectations about future macroeconomic conditions, the economy is in the “unstable” region where adaptive learning reinforces pessimistic expectations, we implement the following treatments. In one treatment, denoted as “Severe Pessimism” (P) in Table 1, we try to affect the starting level of pessimism in the experimental economy. Recall that, as the experiment requires two-period-ahead-forecasts, subjects are asked at the start of the experiment to enter forecasts for periods 1 and 2 simultaneously. At the beginning of the experiment, subjects receive some indication of initial values, being informed in the instructions that in similar economies, inflation and net output have historically been within a certain interval. In order to reproduce a situation of “Severe Pessimism” (P), we provide the historical range of $[0.92, 1.08]$ for inflation (given a targeted steady state of 1.05) and the historical range of $[0.50, 0.80]$ for net output (given a targeted steady state of about 0.74). In this treatment, the point with coordinates given by the mid-points of the historical ranges, i.e. $\{1, 0.65\}$, which typically acts as a focal point for subjects’ forecast in the initial phase of the experiment, lies in the “unstable” region.

In the other treatment, labelled as “Expectational Shocks” (S) in Table 1, the historical range provided to subjects in the instructions is $[0.95, 1.08]$ for inflation, and $[0.60, 0.80]$ for net output. In this case the focal point for initial expectations, i.e. $\{1.015, 0.7\}$, lies in the “stable” region under adaptive learning, leading to convergence to the targeted equilibrium. Therefore, in order to provoke an expectational shock, some “bad news” pop up on the participants’ screen in the form of newspaper reports with experts’ opinions about future economic conditions (see Experimental Instructions in Appendix C for details).¹⁵ Subjects are informed in the instructions that a newspaper is operating in the economy which may announce from time to time news about experts’ opinions on the economy, and we explicitly

¹⁵Notice also that subjects in the *Severe Pessimism* treatments were also informed about the possibility of news announcements, so experimental instructions were the same for both the *Severe Pessimism* and the *Expectational Shocks* treatments, with the exception of the historical ranges for inflation and net output. No news announcements appeared in the *Severe Pessimism* treatments.

tell subjects that the experts' opinions have no impact on actual realisations of the aggregate variables describing the experimental economy, and that it is up to them to determine whether and how to use the newspaper information. In treatments MS and FS the expectational shocks, i.e., pessimistic news announcements, were repeatedly given in periods 8, 9 and 10, due to the two-period-ahead nature of the forecasting task.

In the context of the second policy regime labeled as “Fiscal Switching” (F) in Table 1, we are interested in testing the effectiveness of the fiscal switching rule in combating liquidity traps. In particular we want to test the following:

Proposition 2. *Under the policy regime F (described by Eqs. (3) and (5)), liquidity traps in the form of deflationary spirals are prevented both in the case of initial severe pessimism (treatment FP), and expectational shocks (treatment FS).*

In our experiment adverse expectations represent the only source of deflationary pressure causing the ZLB to bind, without imposing any large exogenous shock to the fundamentals of the economy. Small fundamental shocks alone (with a standard deviation of 0.0025) cannot push the economy into the unstable region, unless it was already very close to the boundary. Liquidity traps are therefore entirely driven by expectations. Most of the theoretical frameworks used in the literature to think about liquidity trap episodes assume that the economy is pushed at the ZLB as a result of a sustained exogenous negative preference shock modelled as a two-state Markov process with an absorbing value at the “normal” level which, therefore, disappears in finite time (see e.g., Eggertsson and Woodford (2003) among others). On the other hand, our experimental design makes the occurrence of liquidity traps and the potential recovery path completely endogenous and dependent on the policy's impact on expectations' dynamics (see further discussion in Section 5).

3.2 Implementation

The experiment was programmed in Java using the PET software¹⁶ and it was conducted at the CREED laboratory at the University of Amsterdam in October 2014. A total of 168 subjects recruited from the CREED subject pool took part in the experiment (28 experimental economies of 6 subjects each). During the experiment, “points” were used as currency. Points were exchanged for euros at the end of each session at an exchange rate of 0.75 euro per 100 points. The experiment lasted for about two hours and participants earned on average 21.1 euros. The series of small IID shocks buffeting the experimental economies were the same for all groups.¹⁷

4 Experimental Results

4.1 Overview of the results

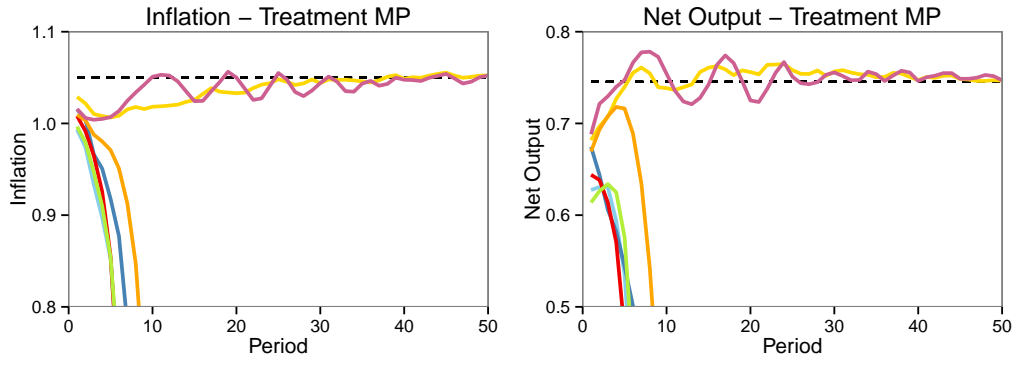
An overview of the experimental results is reported in Fig. 4 (the data for each group including interest rate, government expenditure and expectations dynamics are reported in Appendix A). Each line corresponds to realised inflation (left panels) and net output (right panels) in one experimental economy (7 economies per treatment), tracked over all 50 periods of the experiment.¹⁸

In treatment MP, initial pessimistic expectations lead to realised inflation and net output well below target, causing the central bank to set the interest rate to the ZLB in an attempt to stimulate the economy. In only 2 out of 7 economies this policy measure suffices to ensure recovery, avoiding deep recessions and leading to convergence to the targeted steady state (π^*, c^*) , at least in the long run (see

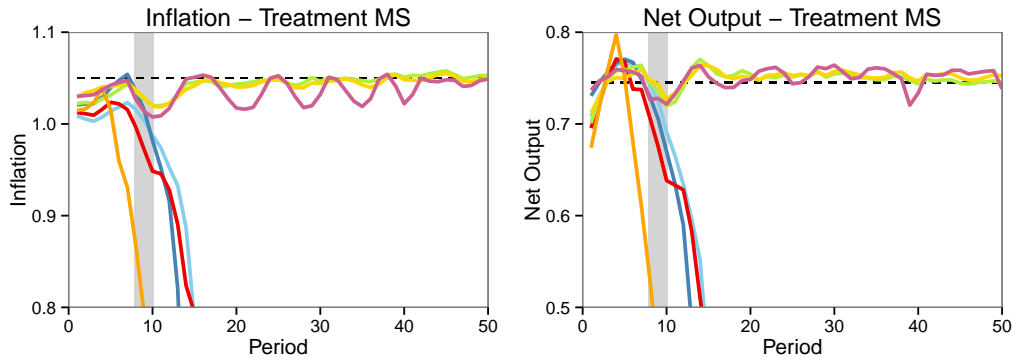
¹⁶PET software was developed by AITIA, Budapest, and is available at <http://pet.aitia.ai>.

¹⁷The actual experiment included one more group that we exclude from the analysis (including this group, the experiment was conducted with 174 subjects). This group was excluded due to severe misunderstandings of one subject who behaved very strangely and made non sensible predictions, systematically far away from actual realisations (thereby also losing a lot of money). The results for this group are reported for completeness in Appendix E.

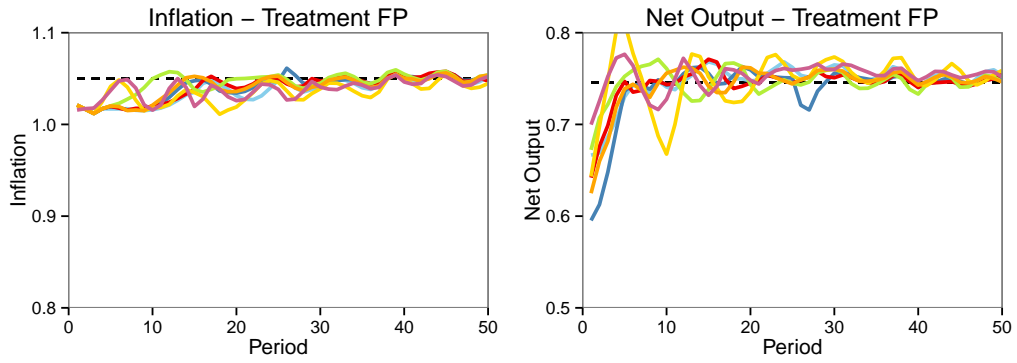
¹⁸Experimental economy 6 in treatment FS ended at period 35 due to a server error.



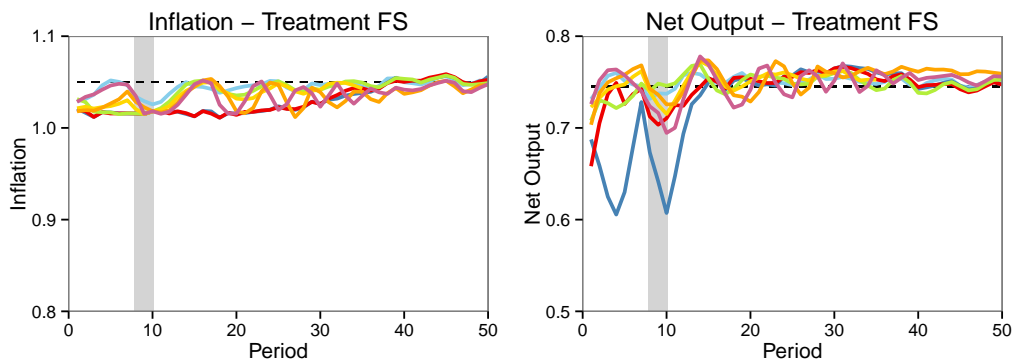
(a) Treatment MP



(b) Treatment MS



(c) Treatment FP



(d) Treatment FS

Figure 4: Overview of experimental results of the 4 treatments, 7 groups each. **Left panels:** realised inflation. **Right panels:** realised net output. Dashed lines depict targeted equilibrium levels. Shaded areas indicate expectational news shocks.

Fig. 4a). In the remaining 5 out of 7 groups, pessimistic expectations are so severe that monetary policy alone is not enough to revert the decelerating inflation path. These economies experience liquidity traps characterised by inflation and output trajectories declining over time. Eventually, inflation and net output expectations hit the lower bound imposed to ensure well-defined model equations, i.e., inflation rate of -20% and net output lower than 50% of the equilibrium value. The ensuing wild oscillations afterwards are not meaningful from an economic point of view and are not reported in Fig. 4a.¹⁹

In treatment MS, all economies start converging to the targeted equilibrium in the initial phases of the experiment. However, the expectational shocks in the form of “bad news” occurring in periods 8 – 10 (shaded areas in Fig. 4b) lead to the emergence of a liquidity trap in 4 out of 7 economies.²⁰ In these groups, the shift in expectations produces sufficient deflationary pressures to cause the ZLB to bind. Low expectations of future inflation imply high real interest rates at the ZLB which, combined with low expected output, imply low realisations of aggregate output and lead to actual inflation below expected inflation. Expectations are revised further downward causing accelerating deflation and deep recessions. Moreover, in one of the three economies that do not fall in a liquidity trap after the adverse expectational shock, the deflationary outcome is avoided thanks to the implementation of the aggressive monetary policy which preventively cut the interest rate and succeeded in stimulating the economy, while in the other two economies the standard Taylor rule suffices in steering the economy towards the desired equilibrium.

In treatments FP and FS we do not observe the occurrence of liquidity traps, neither as a result of initial severely pessimistic expectations, nor as a result of adverse expectational shocks (see Figs.4c – 4d). In fact, in 12 out of 14 economies of treatments FP and FS, the fiscal switching rule is activated and government

¹⁹For the sake of completeness, we reported the complete time series in Appendix A.

²⁰In group 6 the fall in the liquidity trap starts before the expectational shock due to the forecast of one subject who attempted to stop the converging trend in inflation/net output, and it is reinforced by the bad news announcement.

expenditures increase in reaction to low levels of inflation and net output caused by pessimistic expectations (see Figs. 14 – 15 in Appendix A). The expansionary fiscal interventions prevent the experimental economies from falling into liquidity traps, confirming the theoretical results of Evans et al. (2008) and Benhabib et al. (2014). In fact, the fiscal switching rule described in Eq. (5) has an impact on the *expectations feedback system* underlying the experimental economies by interrupting downward trends in inflation and net output caused by very pessimistic expectations.²¹ Observation of realised inflation ($\tilde{\pi}$) above (pessimistic) expectations leads subjects to revise upward their forecasts, implying therefore an increase in inflation and net output. The reversal of the negative trend eventually pushes the experimental economies away from the ZLB, leading to convergence to the targeted steady state. When the fiscal switching rule is implemented, we observe two qualitatively different types of convergence patterns, namely oscillatory convergence to the target (groups 4, 5 in treatment FP and groups 5, 6, 7 in treatment FS) and slow convergence with interest rates at, or close to, the ZLB and inflation stuck at low levels for an extended period of time (groups 1, 2, 3, 6 in treatment FP and groups 2, 3, 4 in treatment FS). The latter scenario can be described as an *almost self-fulfilling* equilibrium (see Hommes (2013)) arising as a consequence of the implementation of the fiscal switching policy. The intuition for the emergence of such (temporary) state is the following. Any downward trend in inflation and expectations below the threshold $\tilde{\pi}$ is interrupted by stabilizing inflation around $\tilde{\pi}$. Therefore, the inflation level $\tilde{\pi}$ may act as an anchor for subjects' expectations preventing on the one hand drops in inflation expectations below such level but not necessarily ensuring a rise of expectations above $\tilde{\pi}$. In other words, the fiscal switching rule may not be enough to quickly *revert* expectations. In fact, while fiscal policy ensures a level of inflation around $\tilde{\pi}$, net output adjusts slowly towards

²¹The importance of the nature of the feedback at play between expectations and realisations has been recognised in earlier experimental works, see e.g., Nagel (1995), Heemeijer et al. (2009), Fehr and Tyran (2008) among others. See also Assenza et al. (2011) for an experimental investigation of the impact of alternative monetary policies on the expectations feedback system in New Keynesian economies.

equilibrium. As long as realisations and expectations of net output are low enough for the fiscal switching rule to be activated, inflation expectations remain focused at $\tilde{\pi}$. However, as net output increases further in the adjustment towards equilibrium, the fiscal rule will be no longer activated and inflation realisations will be above $\tilde{\pi}$. Subjects then revise their inflation expectations upward, until convergence to equilibrium. Therefore adverse expectational dynamics can be very persistent and the recovery driven by the mix of aggressive monetary policy and fiscal policy rule can be slow.

4.2 Learning model predictions

We now turn to the test of the learning model’s predictions in describing the occurrence and characteristics of liquidity trap episodes, summarised in Propositions 1 – 2. Figs. 5 – 7 display experimental data in the (π, c) -space. The plots show the numerical approximation of the stable manifold of the low inflation steady state under the learning dynamics described in Section 2.3 which divides the phase space in two regions, namely the region below the stable manifold labelled as “unstable”, and the region above the stable manifold labelled as “stable”. According to Proposition 1, expectations which are pessimistic enough to fall in the “unstable” region lead to the occurrence of a liquidity trap in the form of a deflationary spiral in treatments MP and MS, while according to Proposition 2 liquidity traps should never occur in treatments FP and FS when the fiscal switching policy regime is implemented.

Severely pessimistic expectations are induced in treatment MP at the beginning of the experiment by providing historical ranges for inflation and net output such that middle points of the intervals lie in the “unstable” region. Fig. 5a plots subjects’ average expectations in period 2 for the seven experimental economies in treatment MP.²²

²²We plot average expectations in period 2 (for period 3) because this is the first period in which subjects observe realised inflation and net output, receiving therefore a feedback on their forecasts and having a clearer idea of the order of magnitudes of inflation and net output.

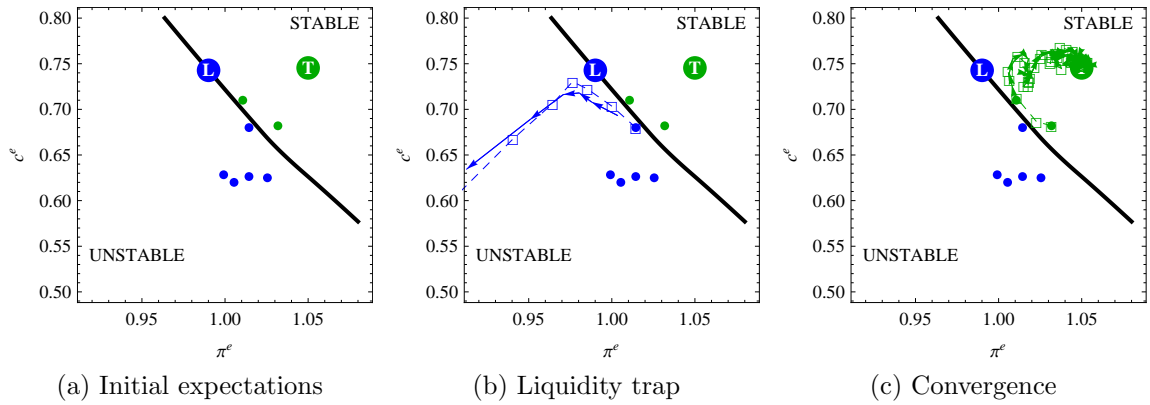


Figure 5: Treatment MP

The five blue points correspond to experimental economies that experience a liquidity trap, while the two green points correspond to the experimental economies that converge to the targeted equilibrium. From the graphical analysis it is clear that all economies in which initial expectations are pessimistic enough to lie in the “unstable” region fall in a liquidity trap, while all economies in which expectations are less pessimistic and lie instead in the “stable” region converge to the target. Additionally, Fig. 5b provides a typical example of deflationary dynamics (group 6) and Fig. 5c a typical example of converging dynamics (group 5). In Figs. 5b and 5c, solid lines refer to realisations of inflation and net output while dashed lines depict the dynamics of average subjects’ expectations. Fig. 5b shows that the initial stimulus provided by the aggressive monetary policy which sets the interest rate to the ZLB from the beginning of the experiment in reaction to very pessimistic expectations causes an initial rise in net output. However the stimulus to the economy deriving from the accommodative monetary policy is not enough to offset very pessimistic expectations. Deflationary expectations lead in fact to high real interest rates causing eventually both inflation and net output to fall, in the direction of the unstable manifold of the low inflation steady state L.

Fig. 6 refers to treatment MS. In this treatment initial expectations are only mildly pessimistic, in the sense that the middle points of the historical ranges for inflation and net output provided to subjects in the instructions lie in the “sta-

ble” region. Therefore, as expected, initial average forecasts in all experimental economies lie in the “stable” region as shown in Fig. 6a and all groups start converging to the targeted steady state.

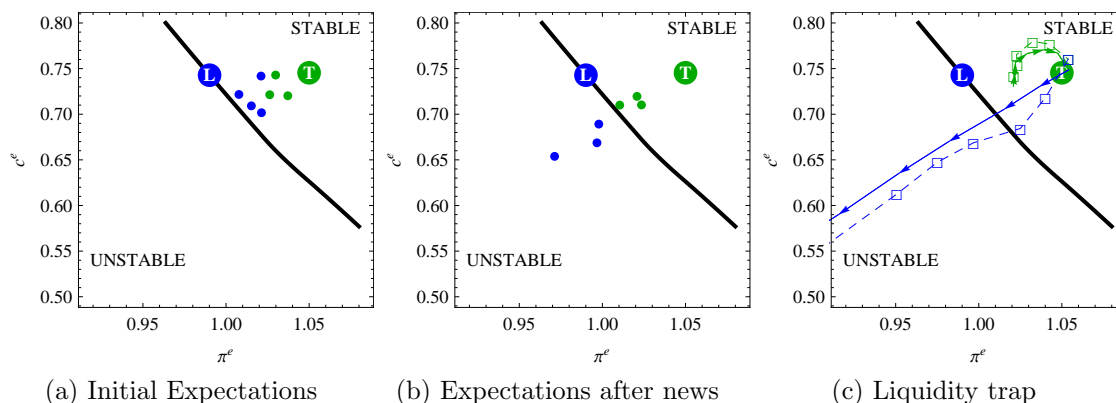


Figure 6: Treatment MS

However, the expectational shocks lead to a shift in the average sentiment about the economic conditions, causing expectations to move towards the bottom left corner of the phase space, i.e., lower expected inflation and net output. Fig. 6b plots average expectations after the expectational shocks (period 11) for all experimental economies in treatment MP. All groups in which expectations are pushed in the “unstable” region (characterised again by blue points) fall in a liquidity trap, while all economies in which expectations remain in the “stable” region eventually recover and converge to the targeted equilibrium.²³ Fig. 6c displays a typical example of deflationary dynamics following the expectational shocks in group 2 (once again solid lines refer to actual inflation and net output dynamics while dashed lines depict dynamics of expectations). The green lines show the dynamics of aggregate variables and expectations before the expectational shocks, clearly converging to the target. After the “bad news” announcements, expectations shift downward (blue dashed line), entering the “unstable” region and starting a self-reinforcing process leading to collapse of output and deflationary outcomes (blue solid line).

²³As mentioned above, in one experimental economy (group 6) the fall in the liquidity trap starts before the expectational shocks and thus, by period 11, expectations are beyond the boundaries of Fig. 6b, explaining why we only observe 6 instead of 7 points.

Fig. 7 refers to treatments FP and FS, in which the fiscal switching policy rule is implemented. Fig. 7a displays the average initial expectations in all economies of treatment FP, characterised by initial severe pessimism, while Fig. 7b displays the average forecasts after the expectational shocks (in period 11) in all economies of treatment FS.

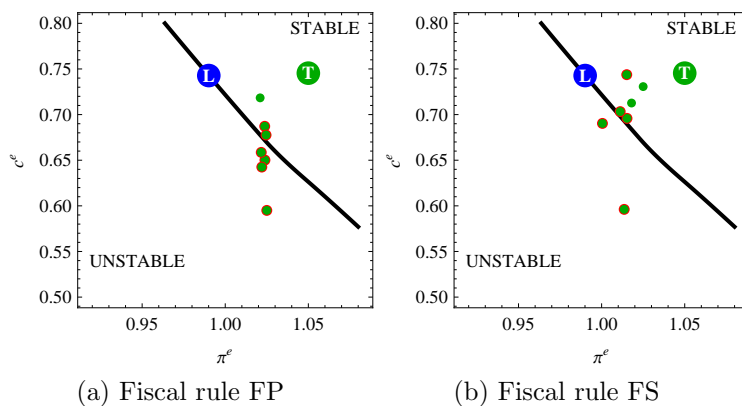


Figure 7: Treatments FP (left) and FS (right)

In both figures, all points are represented in green as all groups converge to the targeted steady state. Points circled in red refer to experimental economies in which the fiscal switching rule has been activated. Several points lie in the “unstable” area, indicating that these economies might have fallen in a liquidity trap in the absence of an active fiscal switching rule.

Fig. 8 compares the experimental data with adaptive learning. The figure depicts the solutions of the differential equation (10) governing adaptive learning under decreasing gain (solid black lines), as well as simulated expectations paths for the limiting case of naive expectations $\delta = 1$ (red points), together with the actual expectations dynamics observed in the experiment (blue and green squares). Fig. 8a refers to the example of liquidity trap observed in treatment MP and previously described in Fig. 5b; Fig. 8b refers to the example of convergence to target in treatment MP depicted in Fig. 5c, while Fig. 8c corresponds to the example of liquidity trap caused by “bad news” announcement in treatment MS reported in Fig. 6c.

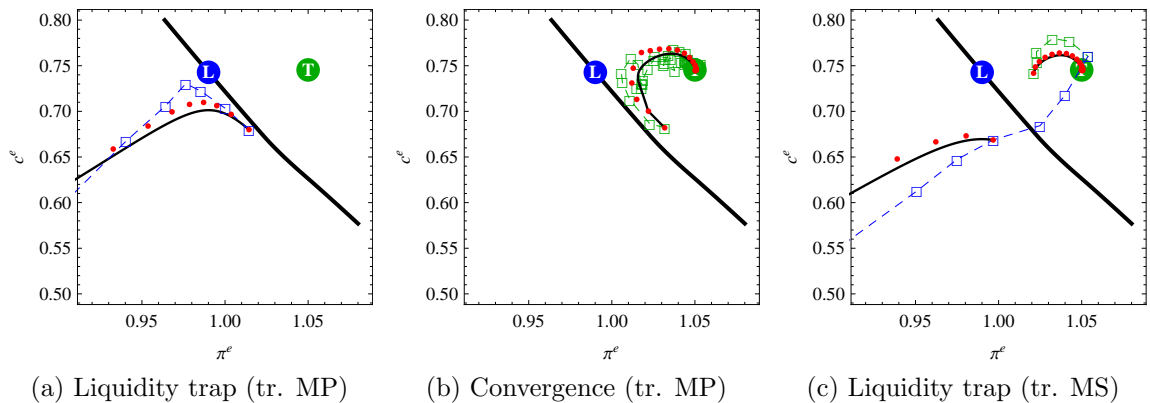


Figure 8: Simulated expectations dynamics under decreasing gain (solid black lines) and constant gain $\delta = 1$ (red points), experimental data converging to the targeted steady state (green squares), and deflationary spirals (blue squares).

Overall, we find that the predictions of the adaptive learning model in describing the occurrence of liquidity trap are validated by the experimental results. In particular, we find that under the policy regime (3) – (4), adverse expectations caused either by a severe level of initial pessimism or by an expectational shock, lead to the emergence of liquidity traps in the form of deflationary spirals (Proposition 1). An aggressive monetary policy alone, which preventively cuts the interest rates to the ZLB when inflation falls below a certain threshold, is not enough to avoid liquidity traps. E-stability under learning rules (8) – (9) provides a rather accurate description of how pessimistic expectations need to be for the economy to fall in a liquidity trap, or in other words, a prediction of when the stimulus provided by monetary policy, as a function of average expectations, is enough to avoid deflationary outcomes. If average expectations fall in the “unstable” region, the presence of the ZLB makes monetary policy alone powerless at correcting adverse expectations dynamics and avoiding liquidity traps. On the other hand, our experimental results suggest that an aggressive monetary policy augmented with a fiscal switching rule can be successful in affecting the expectations feedback system and prevent the occurrence of deflationary outcomes (Proposition 2).

In the next section we analyse the quantitative effects of fiscal policy in the experimental economies.

4.3 Estimation of the Impact of Fiscal Policy at the ZLB

We now analyse the impact of temporary increases in public expenditures on output in the experimental economies. In particular, we are interested in estimating the effect of fiscal policy at the ZLB. We therefore consider economies in treatments FP and FS in which the fiscal switching rule has been activated while the interest rate is set at the ZLB. In order to obtain a proxy for the fiscal multiplier in our experimental environment where no a-priori assumptions are made on how agents form expectations and where we verified that liquidity trap episodes take the form of deflationary spirals, we use data from economies that fell in a liquidity trap due to a binding ZLB in treatments MP and MS as counterfactual. In particular, following the empirical approach of Aruoba et al. (2013), we compute the multiplier

$$\mu_t^* = \frac{\bar{y}_{t+1}^{F*} - \bar{y}_{t+1}^{M*}}{\bar{g}_t^{F*} - \bar{g}}, \quad (13)$$

respectively for economies where the binding ZLB is caused by initial severe pessimism ($* = P$) and expectational shocks ($* = S$). In Eq. (13), \bar{y}_{t+1}^F denotes the value of output ($y = c + g$) in period $t + 1$ averaged over economies in each treatment $*$ where the fiscal switching rule has been activated in period t , \bar{y}_{t+1}^M denotes the value of output averaged over economies in each treatment $*$ that experienced a liquidity trap due to a binding ZLB, and \bar{g}_t^F refers to the value of government expenditures, averaged over the economies in each treatment $*$ under the fiscal rule in Eq. (5). Notice that in the numerator of Eq. (13) we included the values of output realised in period $t + 1$, i.e., immediately after the fiscal shock g_t . This is due to the fact that realisations of net output in period t are not affected by public expenditures in period t (see Eq. (1)), but only depend on expectations formed at the beginning of period t , i.e., before the implementation of fiscal policy. The values of the multipliers for treatments FP and FS are reported respectively in Fig. 9 and 10.

The cumulated multiplier over periods 1 – 4 for treatment FP is about 1.77,

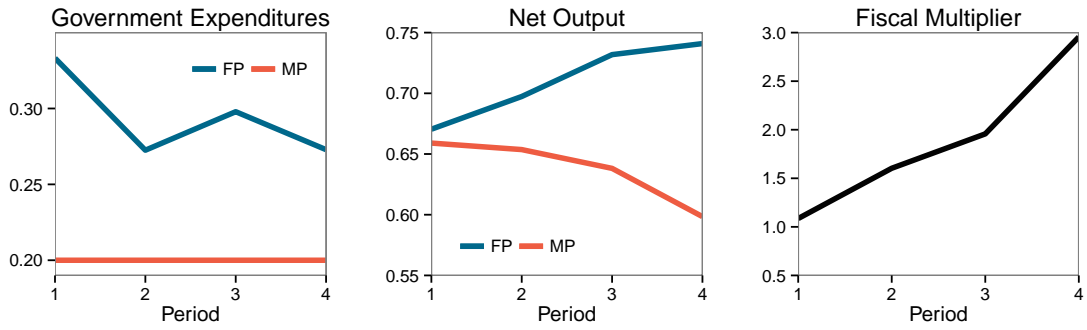


Figure 9: Treatment FP. **Left panel:** Government Expenditures. **Middle panel:** Net Output. **Right panel:** Fiscal multipliers.

while for treatment FS the cumulated multiplier over periods 8 – 10 is roughly 1.1. Overall, the estimated values above 1 suggest that expansionary fiscal policy crowds in private consumption through a rise in inflation expectations (which decreases the real interest rate) and a rise in expected net output.

The difference in the magnitude of the multiplier between the two treatments is due to the following. In treatment MS the bad news shocks causing pessimistic expectations occur in periods 8 – 10, i.e. when the economies are already converging towards the intended equilibrium and expectations are of course in the “stable” region. Therefore, in the initial phases of the expectational shift, output and inflation do not drop dramatically as beliefs are still within the “stable” region. It is only after the last bad news announcements that expectations fall in the “unstable” region, triggering thus an accelerating deflationary process and large drops in output. These periods of deep recession leading to higher values of the numerator in Eq. (13) do not have an impact in the computation of the multiplier as typically the fiscal switching rule succeeds in creating inflationary expectations immediately after the last expectational shock. On the other hand, in treatment MP expectations are severely pessimistic, i.e. within the “unstable” region, already at the beginning of the experiment, implying high perceived real interest rates and causing large drops in consumption, which lead to higher values of the numerator in Eq. (13).

In the computation of the multiplier for treatment FS we did not include group

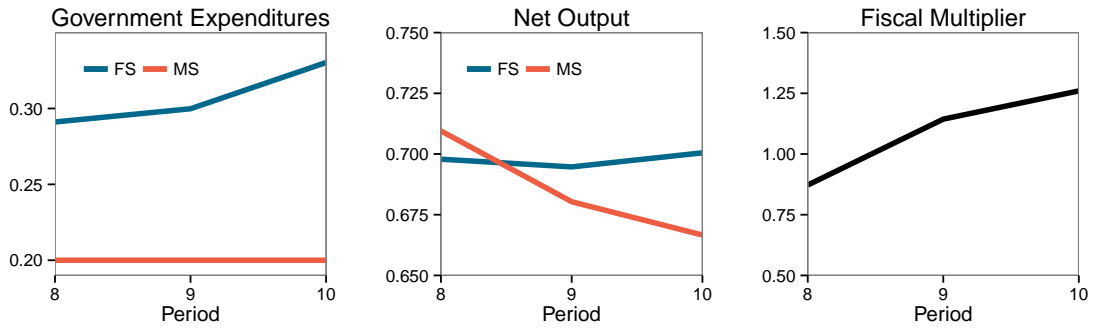


Figure 10: Treatment FS. **Left panel:** Government Expenditures. **Middle panel:** Net Output. **Right panel:** Fiscal multipliers.

6 from treatment MS in the counterfactual data because the process leading to the fall in the liquidity trap started before, and got reinforced by, the “bad news” announcement (see footnote 20). Levels of net output were already much lower than average by the time the first expectational shock hit the economy due to increasingly pessimistic expectations’ dynamics in the “unstable” region. Inclusion of group 6 in the computation of the multiplier leads to an estimated cumulated multiplier of about 1.65. Therefore the magnitude of the multiplier increases when the fiscal policy rule is activated in reaction to accelerating deflationary pressures in the “unstable” region.

5 Discussion

In this section we compare our results on the effect of fiscal policy at the ZLB with the existing literature and, in the light of our findings, we briefly comment on the recent policy debate on whether the FED should raise its target interest rate in the short/medium run.

5.1 Related literature on fiscal multipliers

There are only few, and no consensual estimates of the fiscal multipliers during a recession in the literature. This is mainly due to technical difficulties (see Parker (2011) for a discussion). Episodes of deep recessions are rare and thus available

data are limited. Furthermore, fiscal multipliers are usually estimated using linear VAR models or linearized DSGE models, which do not allow for state-dependence and non-linearities between the output effects of government spending and the size of the fiscal action. On the empirical front, one exception is Auerbach and Gorodnichenko (2012). Using a structural VAR model with regime switching, they find that fiscal multipliers are much higher in recessions than in expansions and conclude in favour of values ranging between 1 and 1.5 in a recession (see also Tagkalakis (2008) and Braun et al. (2012)). On the theoretical front, once accounting for the zero-lower bound in a DSGE model, fiscal multipliers may be typically larger than one during economic downturns, especially when the ZLB is binding (Christiano et al. (2011)), or if the liquidity trap is expected to be long-lasting (Erceg and Lindé (2014)). Christiano et al. (2011) find values as high as 3.7 in their baseline model. Furthermore, Mertens and Ravn (2014) find larger multiplier values on the transitory adaptive learning dynamics towards rational expectations equilibrium than in the case of rational expectations.²⁴ In our experiment the estimated values of the fiscal multipliers at the ZLB are largely consistent with these findings. Moreover, we stress that the expectational channel of fiscal policy is crucial in our experimental setting. In fact, in our experimental economies, net output c is not directly influenced by g (see Eq. (1)), but depends on expected net output and the real interest rate. The possibility for fiscal policy to crowd in or out private consumption then works entirely through the *expectation feedback mechanism*.

Analysing how policies affect this expectation feedback mechanism in a set-up where the occurrence of liquidity traps and the time to the recovery are endogenous, and no specific assumption has to be made on expectations is one of the major contributions of our experiment. This approach contrasts with most models of liquidity trap *à la* Eggertsson and Woodford (2003). In those models, an exogenous shock causes the ZLB to bind, and fiscal policy aims at mitigating the output losses in the liquidity trap which lasts for an exogenous, *policy-invariant* period of time.²⁵

²⁴However, their estimate are lower than one in both cases.

²⁵Exceptions include Evans et al. (2008), Erceg and Lindé (2014) and Aruoba et al. (2013).

However, the model properties and the policy implications can be quite sensitive to this design (Aruoba et al. (2013)). In such a framework, Mertens and Ravn (2014) contrast confidence-driven and fundamental-driven liquidity traps, and show on the contrary that fiscal stimulus is deflationary in a confidence-driven liquidity trap. One crucial difference with our experimental approach, though, is that liquidity traps arise endogenously in the experiments, and the policy mix influences the economy through the expectation feedback mechanism, which in turn endogenously determines the transitory dynamics along the recovery. The impact of fiscal policy and the expectations' dynamics observed in our experiment are therefore closer to the effects of fiscal policy discussed in Eggertsson (2010): fiscal expansion can counteract a deflationary spiral by creating inflationary pressures, which translate into a drop in the real interest rate if the ZLB is binding, and stimulate private consumption. In this case, the fiscal multiplier can be larger than one at the ZLB due to the impact of fiscal policy on expectations.

5.2 Should the FED raise the target interest rate?

Recent policy debate has focused on whether the FED should raise its benchmark interest rate in the short/medium run. Some economists suggested that mid-2015 would be a good timing, while others suggested to postpone the implementation of the policy measure to 2016 (see minutes FOMC Meeting March 2015). However, in the minutes of the FOMC meeting at the time of writing (April 2015) it is stated that:

Consistent with its previous statement, the Committee judges that an increase in the target range for the federal funds rate remains unlikely at the April FOMC meeting. The Committee anticipates that it will be appropriate to raise the target range for the federal funds rate when it has seen further improvement in the labor market and is reasonably confident that inflation will move back to its 2 percent objective over the medium term. This change in the forward guidance does not indicate that the Committee has decided on the timing of the initial increase in the

target range.

Although the Fed removed from its statement an assurance to "be patient" when considering an initial bump in its near-zero benchmark rate, Fed Chair Janet Yellen told Congress that to raise rates, Fed officials must simply be "reasonably confident" that inflation will drift toward the Fed's target in the medium-term. Accordingly, some economists suggest to remain cautious about raising rates "until you see the whites of inflation's eyes". For example, Krugman states that "if it turns out that the Fed has waited a bit too long, inflation might overshoot 2 percent for a while, but that wouldn't be a great tragedy, but if the Fed moves too soon, we might end up losing millions of jobs we could have had."

We can use the framework described in Section 2.3 to evaluate the proposal of raising the interest rate. A bump in the interest rate, given inflation below the threshold $\tilde{\pi}$, i.e., before the implementation of a state dependent Taylor rule, corresponds to an increase in \tilde{R} in the policy rule described by Eq. (3). Possible consequences of this policy measure are described in Fig. 11.

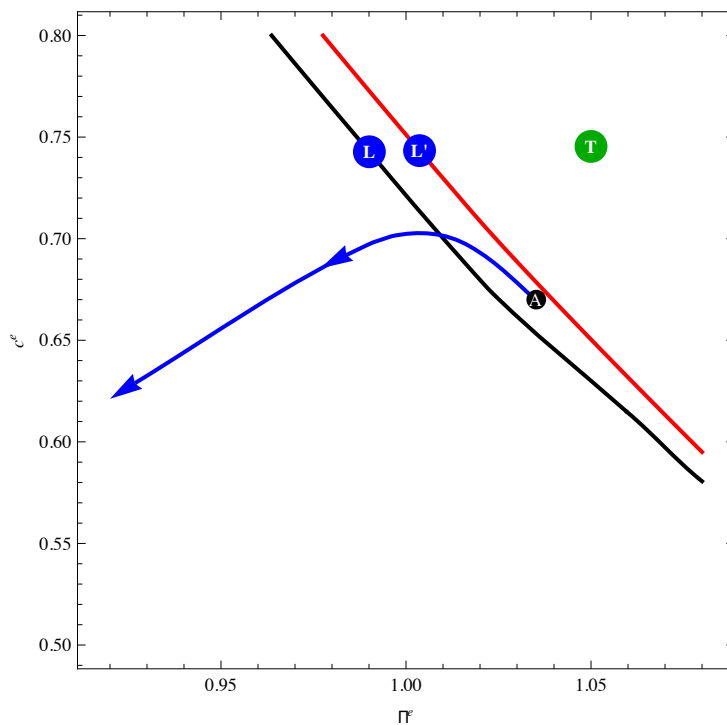


Figure 11: Effect of interest rate's raise.

Suppose expectations are still below target but fall within the "stable" region

before the policy implementation, say at point A. From this point, the economy would probably follow a recovery path leading to the targeted equilibrium. An increase in the rate \tilde{R} moves the low-inflation steady state from point L to L', and thereby causes an upward shift of the stable manifold. After the implementation of the new policy point A lies in the new “unstable” region. The increase in the interest may potentially trigger adverse macroeconomic dynamics and push the economy on a deflationary path. Although highly stylised, the dynamics in this simple model and our empirical experimental evidence confirm Krugman’s view about the disruptive potential of such raise in the interest rate and provide a rationale for a prudent FED’s policy.

6 Conclusions

The aftermath of the 2007-8 experiences, as well as the earlier case of Japan since the 1990s, have underscored concerns about deflation and appropriate policy design when nominal interest rates are constrained by the ZLB. In this paper we use a controlled laboratory environment where expectations’ dynamics are directly elicited from paid human subjects as a test bed for policies against deflationary outcomes. In particular, we use a LtFE to evaluate the effectiveness of monetary and fiscal policies aimed at combating expectations-driven liquidity traps.

Our results show that, in line with the results obtained in the adaptive learning macro literature, liquidity traps in the form of deflationary spirals can emerge as a result of severely pessimistic expectations, even if monetary policy preventively cuts the interest rate when inflation threatens to fall below a certain threshold. In the experiment, adverse expectational shifts create the possibility of a self-reinforcing feedback loop in which sufficiently pessimistic expectations result in low output and inflation, leading to high real interest rates because of the ZLB, which then causes a downward revision of expectations, strengthening the downward pressure on output and inflation.

On the contrary, the implementation of a fiscal switching rule at the ZLB which adjusts upward public expenditures when inflation threatens to fall below a certain threshold is successful in avoiding the occurrence of liquidity traps. We find that fiscal interventions may lead to oscillatory convergence to target as well as to almost self-fulfilling equilibria, i.e., long transition dynamics in which inflation remains below target and interest rate are near the ZLB for an extended period of time before converging to the targeted steady state.

We further analyse the impact of fiscal policy at the ZLB, finding values of the fiscal multiplier larger than one. We emphasise that the ability of fiscal stimulus to crowd in private consumption works through the expectation feedback mechanism in the experimental economies.

We also briefly discuss the recent policy proposal of increasing the FED rates in the US in the light of the experimental results. Evidence from our experimental economies suggests prudence in implementing such policy, in line with the actual strategy of the FOMC.

In general, macro laboratory experiments provide a useful complementary tool to test the effectiveness of monetary and fiscal policies in stylized macroeconomic environments with human subjects.

Finally, the model underlying our experiment is based on so-called “Euler equation learning”, where dynamics of inflation and output are given by the necessary smoothness conditions for optimal decision making. This is a valid and convenient approach to implement in the lab, as it only involves one-step ahead subjects’ forecasts. Preston (2005) introduces an alternative approach, namely “infinite-horizon learning”, in which agents forecast the whole time path of future resources to decide upon their current level of consumption, and re-optimize their behavior in each period.²⁶ Considering infinite-horizon learning is especially useful in the context of fiscal policy, as it allows to consider private sector’s perceived wealth effects of fiscal policy, e.g., the effect of temporary increases in public expenditures on fu-

²⁶See Honkapohja et al. (2013) for a comparison between Euler and infinite horizon learning.

ture expected taxes, which may mitigate the demand stimulus. The type of policy mix considered in our experiment has been analysed under adaptive learning in an infinite-horizon framework in Benhabib et al. (2014), and the authors reach very similar conclusions as under Euler equation learning. Implementing this infinite horizon framework in a laboratory environment requires a more complicated experimental design, involving additional expectational variables to be forecast by subjects over a long horizon. This constitutes an interesting and natural follow-up to the current experiment, which is left for future research.

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Appendix

A Experimental Results

Figs. 12 – 15 report the experimental results for each group in all treatments. In Figs. 12 – 15, the left panels contain the time series of realised inflation (thick solid gold lines), average inflation forecasts (dashed black lines) and interest rate (solid red line), while the right panels contain the time series of realised net output (thick solid gold lines), average net output forecasts (dashed black lines) and government expenditure (scaling on right y-axis) when the fiscal switching rule is implemented, i.e., in treatments FP and FS, (red solid lines). The horizontal dashed lines depict the targeted values of inflation (left panels) and net output (right panels). The shaded areas in Figs. 13 and 15 denote the periods in which expectational shocks in the form of “bad news” announcements occur.

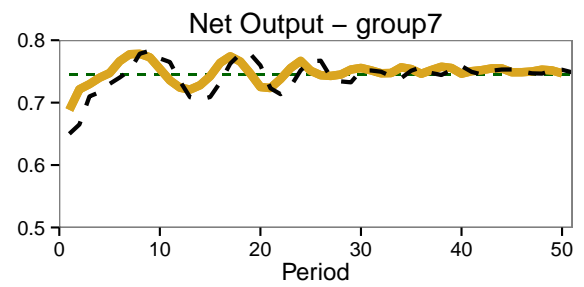
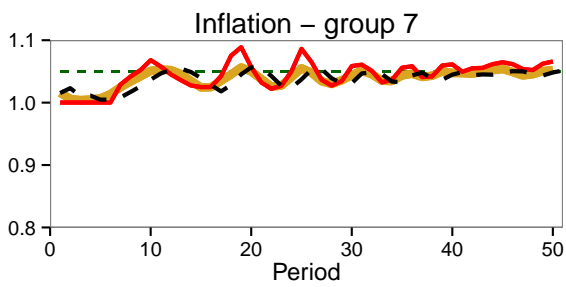
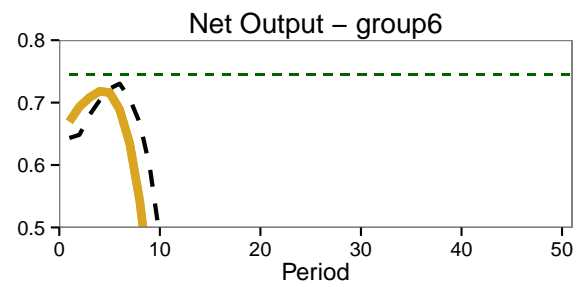
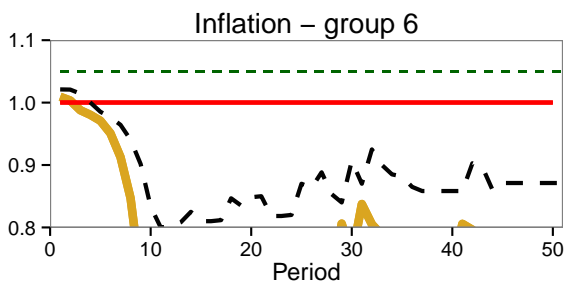
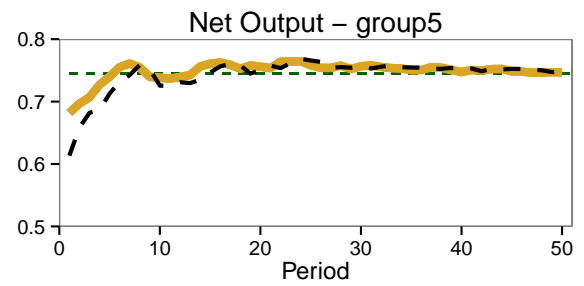
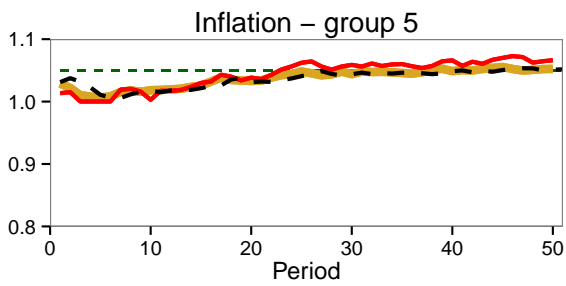
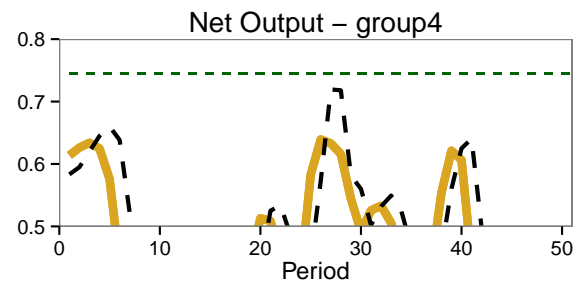
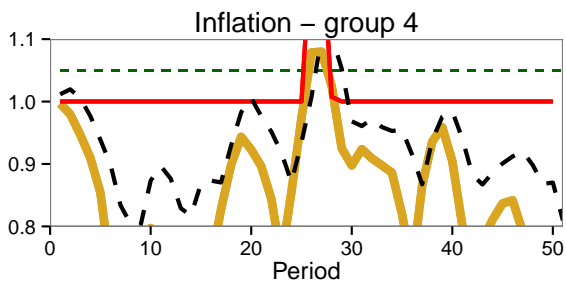
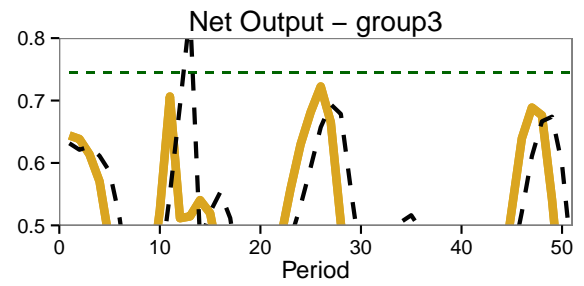
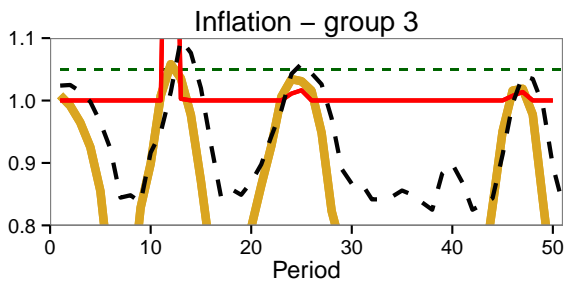
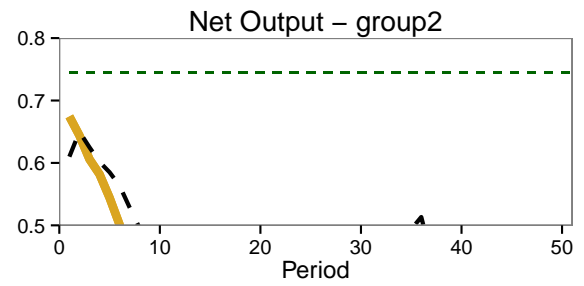
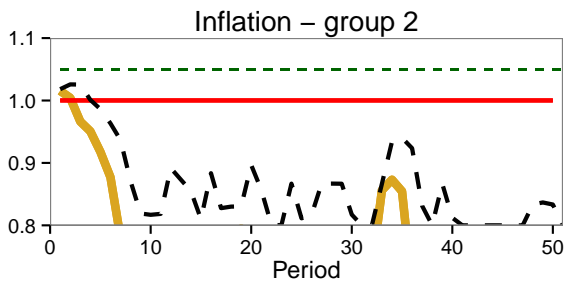
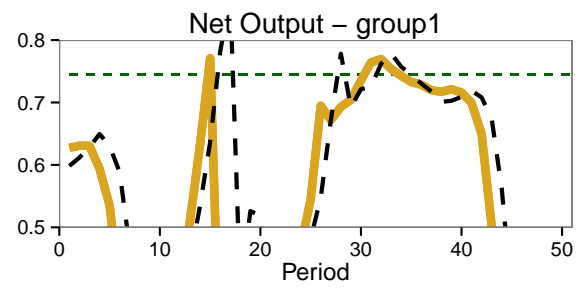
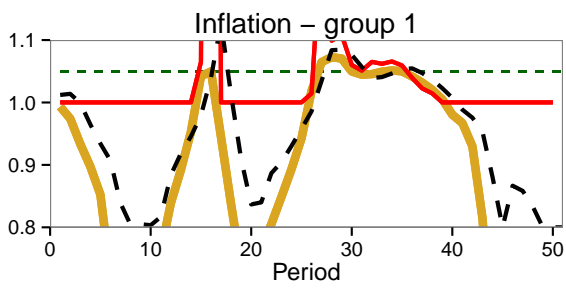


Figure 12: Treatment MP

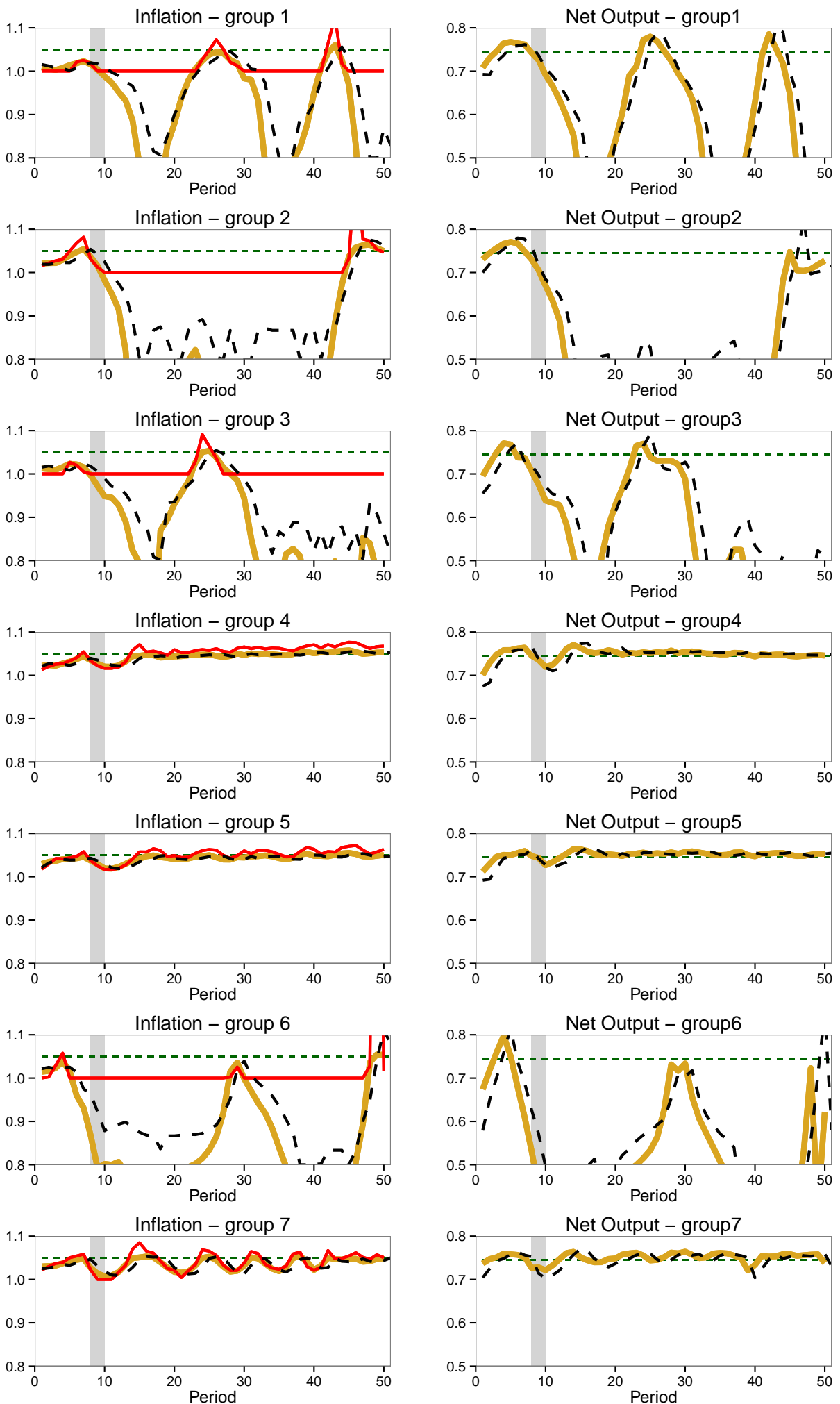


Figure 13: Treatment MS

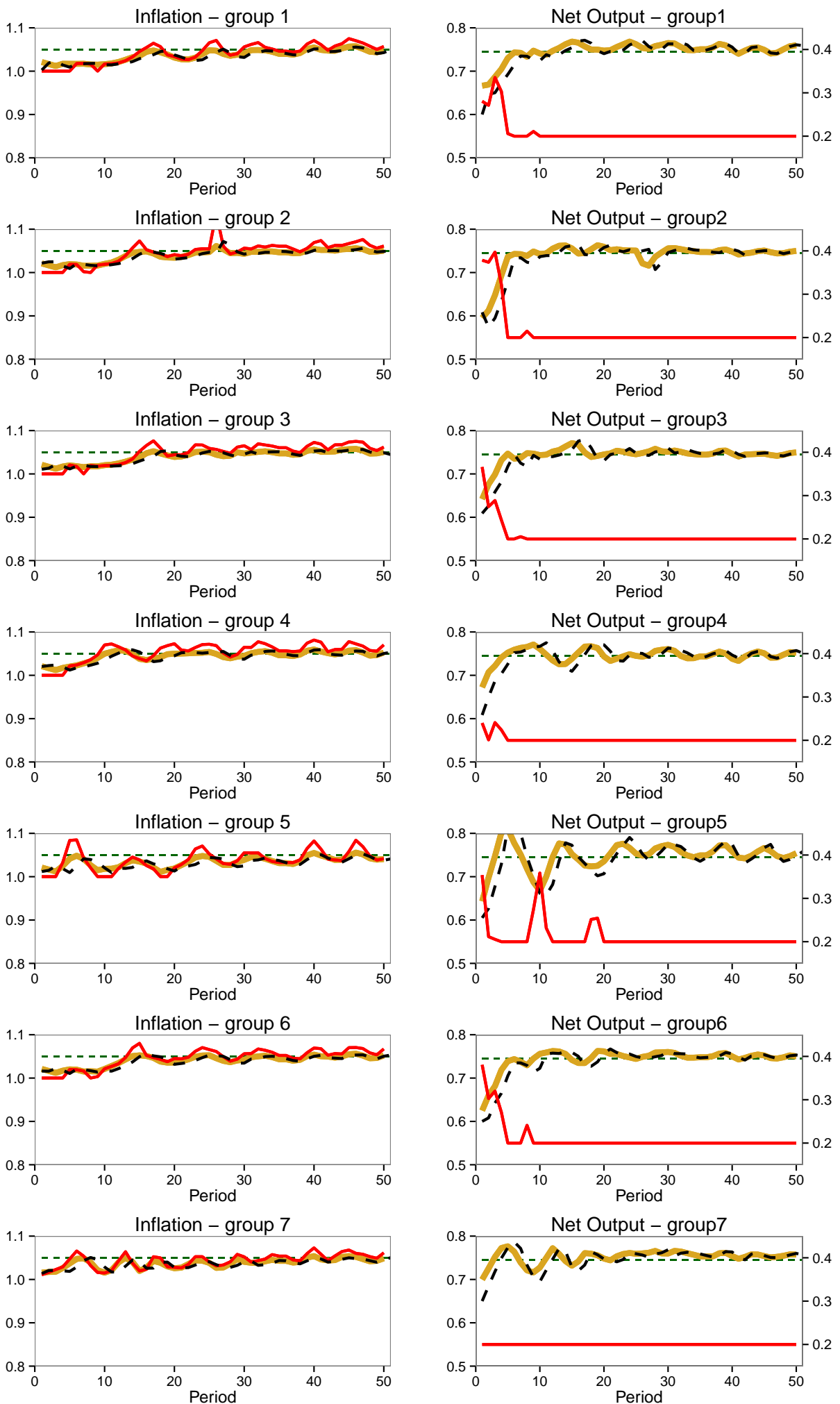


Figure 14: Treatment FP

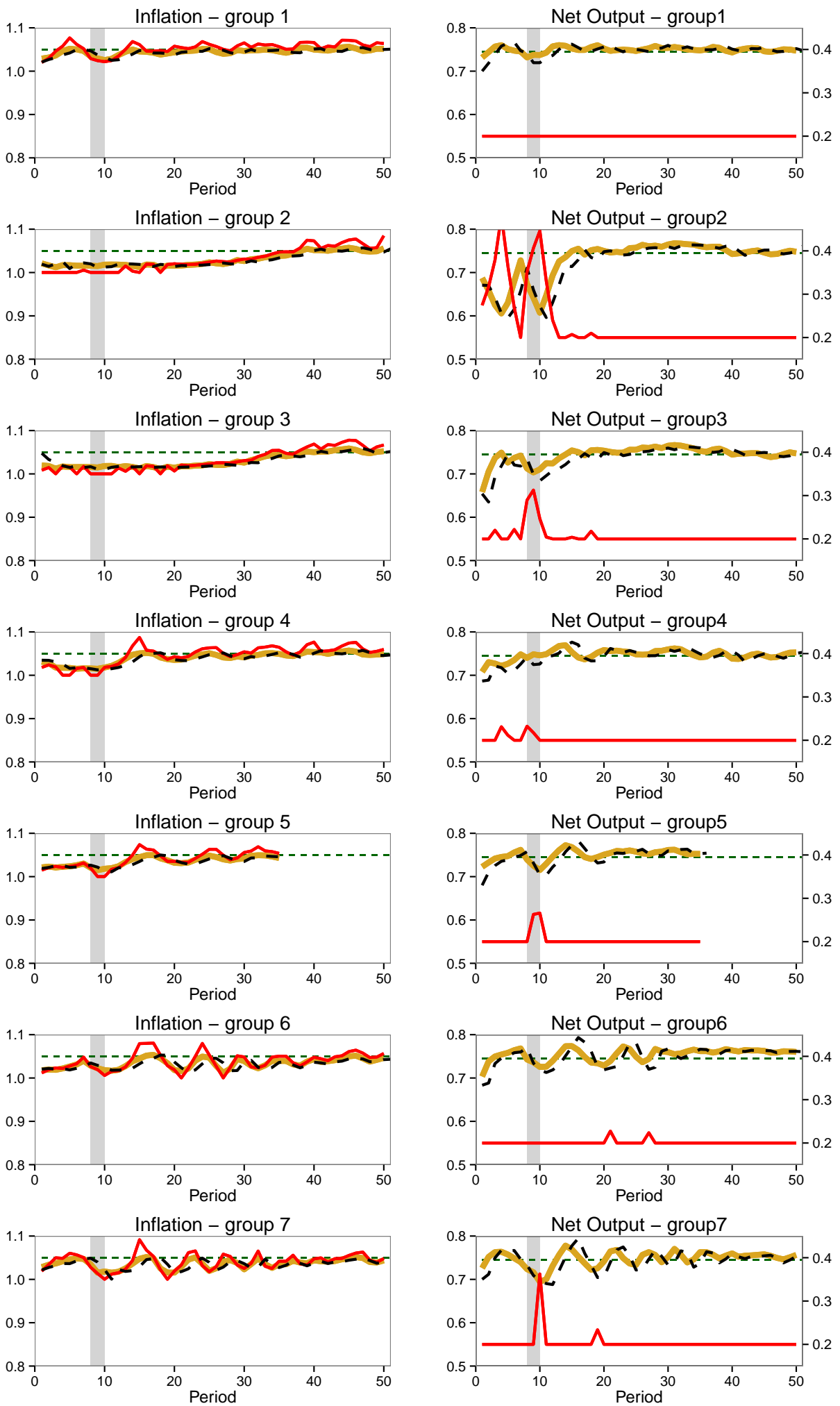


Figure 15: Treatment FS

Appendix (For Online Publication Only)

B Derivation of the NK model

We provide a detailed description of the micro-foundations of the theoretical model underlying the experiment. The derivation is based on the paper Evans et al. (2008), to which the interested reader is redirected for further details.

Private sector

The objective function of firm-household j is given by:

$$\begin{aligned} \text{Max} \quad & E_0 \sum_{t=0}^{\infty} \beta^t U_{t,j} \left(c_{t,j}, \frac{M_{t-1,j}}{P_t}, h_{t,j}, \frac{P_t}{P_{t-1}} - 1 \right) \\ \text{s.t.} \quad & c_{t,j} + m_{t,j} + b_{t,j} + \Lambda_{t,j} = m_{t-1,j} \pi_t^{-1} + R_{t-1} \pi_t^{-1} b_{t-1,j} + \frac{P_{t,j}}{P_t} y_{t,j} \end{aligned} \quad (14)$$

where $c_{t,j}$ is the Dixit-Stiglitz consumption aggregator, $M_{t,j}$ and $m_{t,j}$ denote nominal and real money balances, $h_{t,j}$ is the labor input into production, $b_{t,j}$ denotes the real quantity of risk-free one-period nominal bonds held by the agent at the end of period t , $\Lambda_{t,j}$ is the lump-sum tax collected by the government, R_{t-1} is the nominal gross interest set by the central bank between period $t-1$ and t , $P_{t,j}$ is the price of consumption good j , $y_{t,j}$ is output of good j , P_t is the aggregate price level and gross inflation is defined as $\pi_t \equiv \frac{P_t}{P_{t-1}}$. The subjective discount factor is denoted by $0 < \beta < 1$. The utility function is assumed to have the parametric form:

$$U_{t,j} = \frac{c_{t,j}^{1-\sigma}}{1-\sigma} + \frac{\chi}{1-\sigma_2} \left(\frac{M_{t-1,j}}{P_t} \right)^{1-\sigma_2} - \frac{h_{t,j}^{1+\epsilon}}{1+\epsilon} - \frac{\gamma}{2} \left(\frac{P_{t,j}}{P_{t-1,j}} - 1 \right)^2 \quad (15)$$

with $\sigma, \sigma_2, \epsilon, \gamma > 0$. The final term refers to the price adjustment costs *à la* Rotemberg (1982).

The production function for good j has decreasing returns to scale:

$$y_{t,j} = h_{t,j}^\alpha \quad (16)$$

with $0 < \alpha < 1$. Each firm j operates under monopolistic competition and faces the following demand curve for its differentiated good j :

$$P_{t,j} = \left(\frac{y_{t,j}}{Y_t} \right)^{-1/v} P_t \quad (17)$$

where $P_{t,j}$ is the profit maximizing price set by firm j , $v > 1$ the elasticity of substitution between two goods, and Y_t the aggregate output.

Evans et al. (2008, Appendix A) show that the private sector optimization gives the following key equations:

$$c_t = c_{t+1}^e \left(\frac{\pi_{t+1}^e}{\beta R_t} \right)^{1/\sigma} \quad (18)$$

$$\pi_t(\pi_t - 1) = \beta \pi_{t+1}^e (\pi_{t+1}^e - 1) + \frac{v}{\alpha \gamma} (c_t + g_t)^{\frac{1+\epsilon}{\alpha}} + \frac{1-v}{\gamma} (c_t + g_t) c_t^{-\sigma} \quad (19)$$

$$m_t = (\chi \beta)^{1/\sigma_2} \left(\frac{(1 - R_t^{-1}) c_t^{-\sigma}}{(\pi_{t+1}^e)^{\sigma_2 - 1}} \right)^{-1/\sigma_2} \quad (20)$$

in which the first two equations are the same as Eqs. (1) and (2) governing the law of motion of net output and inflation in the experiment,²⁷ and the third equation implicitly dictates the money demand given the level of net output, the nominal interest rate and expected inflation.

Fiscal and monetary policy

The government budget constraint is given by

$$b_t + m_t + \Lambda_t = g_t + m_{t-1} \pi_t^{-1} + R_{t-1} \pi_t^{-1} b_{t-1} \quad (21)$$

where g_t is the government consumption of aggregate good, b_t the real quantity of government debt, and Λ_t is the real lump-sum tax collected in accordance to a “passive” fiscal policy rule *à la* Leeper (1991):

$$\Lambda_t = \kappa_0 + \kappa b_{t-1} \quad (22)$$

²⁷In order to derive Eq. (19) we used the market clearing condition in the goods market ensuring that $c_t = h_t^\alpha - g_t$.

where the restriction $\beta^{-1} - 1 < \kappa < 1$ ensures that an increase in real government debt leads to an increase in taxes sufficient to cover the increased interest and at least some fraction of the increased principal. In the absence of the fiscal switching rule, g_t is set to some exogenous level $\bar{g} > 0$, while under a fiscal switching regime g_t is set according to Eq. (5). The model is closed by specifying a law of motion for the interest rate, given by the monetary policy rule in Eq. (3).

C Experimental Instructions (Treatment P [S])

Welcome to this experiment! The experiment is anonymous, the data from your choices will only be linked to your station ID, not to your name. You will be paid privately at the end, after all participants have finished the experiment. After the main part of the experiment and before the payment you will be asked to fill out a short questionnaire. On your desk you will find a calculator and scratch paper, which you can use during the experiment.

During the experiment you are not allowed to use your mobile phone. You are also not allowed to communicate with other participants. If you have a question at any time, please raise your hand and someone will come to your desk.

General information and experimental economy

All participants will be randomly divided into groups of six people. The group composition will not change during the experiment. You and all other participants will take the roles of statistical research bureaus making predictions of inflation and the so-called “net output”. The experiment consists of 50 periods in total. In each period you will be asked to predict inflation and net output for the next period.

The economy you are participating in is described by four variables: inflation π_t , net output y_t , interest rate i_t and public expenditure g_t . The subscript t indicates the period the experiment is in. In total there are 50 periods, so t increases during the experiment from 1 to 50.

Inflation (π_t) measures the percentage change in the price level of the economy. In each period, inflation depends on inflation predictions of the statistical research bureaus in the economy (that is on your own forecast as well as on the forecasts of the other

bureaus in the experiment), on net output, on public expenditure and on a small random term. There is a positive relation between the actual inflation and the inflation predictions, the actual net output and the public expenditure. This means that if the inflation predictions of the research bureaus, the actual net output or the public expenditure increase, then actual inflation will also increase (everything else equal). In economies similar to this one, inflation has historically been between -5% [-8%] and 8% .

Net output (y_t) represents the amount of goods produced by firms and consumed by households in the economy. In each period, net output depends on inflation predictions and net output predictions of the statistical research bureaus in the economy (that is on your own forecast as well as on the forecasts of the other bureaus in the experiment), on the interest rate and on a small random term. There is a positive relation between the actual net output and both the inflation and net output predictions. This means that if the inflation predictions or net output predictions of the research bureaus increase, then actual net output will also increase (everything else equal). There is a negative relation between net output and the interest rate. This means that if the interest rate increases, then actual net output will instead decrease (everything else equal). In economies similar to this one, net output has historically been between 60 [50] and 80.

Interest rate (i_t) measures the cost of borrowing money and is determined by the central bank. In each period, if inflation and net output forecasts are considered too high, the central bank increases the interest rate. If inflation and net output forecasts are considered too low, the central bank decreases the interest rate. The interest rate cannot take negative values.

Public expenditure (g_t) measures the amount of goods produced by firms and purchased by the public sector in the economy, and is determined by the government. If actual inflation is considered too low, the government might temporarily increase the public expenditure.

Prediction task

Your task in each period of the experiment is to predict inflation and net output in the next period. When the experiment starts, you have to predict inflation and net output for the first two periods, i.e. π_1^f and π_2^f , and y_1^f and y_2^f . The superscript f indicates that these are forecasts. When all participants have made their predictions for the first two periods, the actual inflation (π_1), the actual net output (y_1), the interest rate (i_1) and the public expenditure (g_1) for period 1 are announced. Then period 2 of the experiment begins. In period 2 you make inflation and net output predictions for period 3 (π_3^f and y_3^f). When all participants have made their predictions for period 3, inflation (π_2), net output (y_2), interest rate (i_2) and public expenditure (g_2) for period 2 are announced. This process repeats itself for 50 periods.

Thus, in a certain period t when you make predictions of inflation and net output for the next period $t + 1$, the following information is available to you:

- realised values of inflation, net output, interest rate and public expenditure, up to and including period $t - 1$;
- Your predictions up to and including period t ;
- Your prediction scores up to and including period $t - 1$.

Additionally, a newspaper operates in this economy, and may announce from time to time news about the opinion of economic experts about future scenarios in the economy. These announcements might pop up on your screen as newspaper reports. The experts' opinions have no impact on actual realisations of the four variables describing this economy, and it is up to you to determine whether and how to use this information. Below you can see examples:



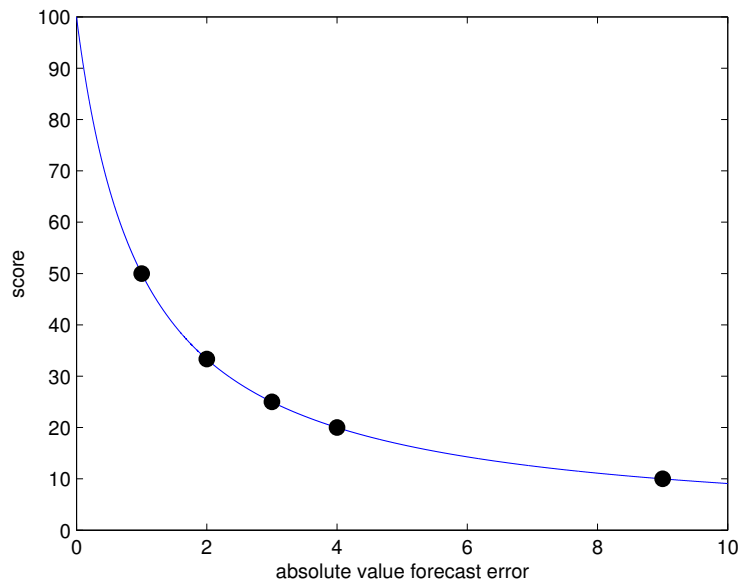
Payments

Your payment will depend on the accuracy of your predictions. You will be paid either for predicting inflation or for predicting net output. The accuracy of your predictions is measured by the absolute distance between your prediction and the actual values (this distance is the prediction error). For each period the prediction error is calculated as soon as the actual values are known; you subsequently get a prediction score that decreases as the prediction error increases. The table below gives the relation between the prediction error and the prediction score. The prediction error is calculated in the same way for inflation and net output.

Prediction error	0	1	2	3	4	9
Score	100	50	33.33	25	20	10

Example: If (for a certain period) you predict an inflation of 2%, and the actual inflation turns out to be 3%, then you make an absolute error of $3\% - 2\% = 1\%$. Therefore you get a prediction score of 50. If you predict an inflation of 1%, and the actual inflation turns out to be negative, for example -2% , you make a prediction error of $1\% - (-2\%) = 3\%$. Then you get a prediction score of 25. For a perfect prediction, with a prediction error of zero, you get a prediction score of 100.

The figure below shows the relation between your prediction score (vertical axis) and your prediction error (horizontal axis). Points in the graph correspond to the prediction scores in the previous table. At the end of the experiment, you will have two total scores, one for inflation predictions and one for net output predictions. These total scores simply



consist of the sum of all prediction scores you got during the experiment, separately for inflation and net output predictions. **When the experiment has ended, one of the two total scores will be randomly selected for payment.**

Your final payment will consist of 0.75 euro for each 100 points in the selected total score (200 points therefore equals 1.50 euro). This will be the only payment from this experiment, i.e. you will not receive a show-up fee on top of it.

Computer interface

The computer interface will be mainly self-explanatory. The top right part of the screen will show you all of the information available up to the period that you are in (in period t , i.e. when you are asked to make your prediction for period $t + 1$, this will be actual inflation, net output, interest rate and public expenditure until period $t - 1$, your predictions until period t , and the prediction scores arising from your predictions until period $t - 1$ for both inflation (I) and net output (N)). The top left part of the screen will show you the information on inflation and net output in graphs. The axis of the inflation graph shows values in percentage points (i.e. 3 corresponds to 3%). **Note that**

the values on the vertical axes may change during the experiment and that they are different between the two graphs – the values will be such that it is comfortable for you to read the graphs.

In the bottom left part of the screen you will be asked to enter your predictions. When submitting your prediction, use a decimal point if necessary (not a comma). For example, if you want to submit a prediction of 2.5% type “2.5”; for a prediction of -1.75% type “-1.75”. The sum of the prediction scores over the different periods are shown in the bottom right of the screen, separately for your inflation and net output predictions. At the bottom of the screen there is a status bar telling you when you can enter your predictions and when you have to wait for other participants.

D Computer Interface

You are player 1

Charts

Information table

Turn	Inflation	Your Inflation Forecast	Net Output	Your Net Output Forecast	Interest Rate	Government Expenditure	Inflation Score	Net Output Score
3		0.80		72.00				
2	0.80	1.50	73.31	70.50	0.01	20.22	53.68	16.77
1	0.77	1.00	71.59	71.00	1.14	20.00	93.81	68.04

Player Actions

You are now in period 3

Enter your forecast for inflation in period 4

Enter your forecast for net output in period 4

Please submit your forecast.

Player Information

Your total score for inflation forecast is 147.50

Your total score for net output forecast is 84.82

Figure 16: Screenshot

E Additional Experimental Results

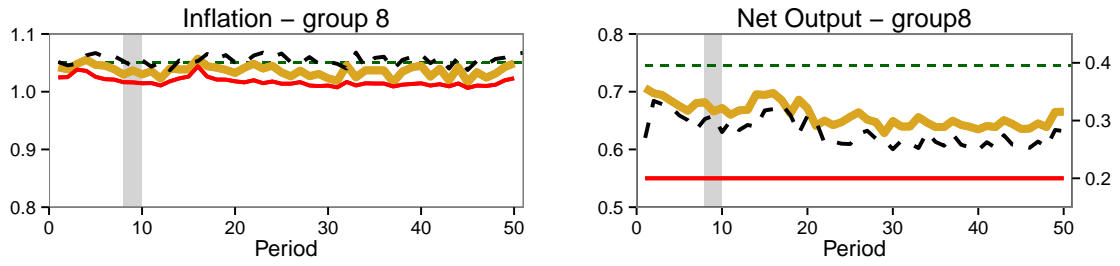


Figure 17: Treatment FS, anomalous group.