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 has pushed many advanced economies into a liquidity trap. We design a laboratory experiment on the effectiveness of policy measures to avoid expectation-driven liquidity traps. Monetary policy alone is not sufficient to avoid liquidity traps, even if it preventively cuts the interest rate when inflation falls below a threshold. However, monetary policy augmented with a fiscal switching rule succeeds in escaping liquidity trap episodes. We measure the effect of fiscal policy on expectations, and report larger-than-unity fiscal multipliers at the zero lower bound. 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 policies in deep recession. In reaction to a sharp fall in aggregate demand and inflation, 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, the ECB cut the interest rate to 0.05% in September 2014, and further to 0% in March 2016, as inflation in the Euro Area has dropped back to 0% (see Fig. 1).

![Figure 1: Macroeconomic scenarios in the Euro Area, US and UK.](image)

This scenario characterised by depressed aggregate activity, low inflation and monetary policy unable to stimulate the economy due to policy rates set at the zero lower bound (ZLB) is referred to as liquidity trap. Recent research developments have described liquidity traps in models with rational expectations (RE) as a second low-inflation equilibrium, in addition to the targeted steady state, generated by “active” Taylor-type interest rate rules subject to a binding ZLB constraint.¹ In models featuring multiple equilibria under RE, stability under learning has often been used as an equilibrium selection device (see Marcet and Sargent (1989) and Evans and Honkapohja (2001) among others), based on the view that RE equilibria...

¹See, for example, Benhabib et al. (2001a,b), Eggertsson and Woodford (2003), Werning (2012) and Mertens and Ravn (2014).
ria 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). Along this line, Evans et al. (2008) and Benhabib et al. (2014) study the stability of these two RE equilibria under adaptive learning, and find that the targeted steady state is locally stable, while the low inflation equilibrium is unstable under learning. Therefore, large pessimistic shocks may result in liquidity traps taking the form of deflationary spirals, along which output and inflation decline over time.\(^2\)

In this paper, we design a series of learning-to-forecast laboratory experiments (LtFEs) in the same environment as Evans et al. (2008), i.e. a non-linear New Keynesian model with multiple RE equilibria. Our goal is twofold: we aim at testing the predictions of a class of learning models in describing the emergence of liquidity traps as a result of adverse expectational shocks, and measuring the effects of monetary and, especially, fiscal policies on expectations.

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), provide an empirical test of theories of expectation formation in a controlled lab environment. In a LtFE, no a priori assumption has to be made regarding the expectation formation process. Expectations are directly elicited from paid human subjects, while all other model assumptions are computerized and, therefore, under the control of the experimenter. Hence, 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 inputs in a New Keynesian model, which describes the dynamics of inflation and output. This sole focus on expectation formation also corresponds to the approach used in the macro learning literature. Furthermore, LtFEs repre-

\(^2\)Evans 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.
sent an interesting method to identify the so-called expectation channel of macro policies, that has been emphasized as a major transmission channel of policies to the economy, while remaining challenging to measure based on field empirical data. LtFEs therefore provide a promising complementary tool to test policy impacts in stylized macroeconomic environments with human subjects.

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 and Zakelj, 2015), disinflationary policies (Cornand and M’Baye, 2013), and the importance of the expectation 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. Closest to our contribution, Arifovic and Petersen (2015) ran a parallel LtFE to study liquidity traps in laboratory economies, but their experimental design differs from ours in the following important dimensions.

First, Arifovic and Petersen (2015) use a linear approximation of the New Keynesian model to describe the experimental economies, while we use the actual non-linear specification. This is a critical difference because linearised models provide an accurate description of the dynamics of the model only in the neighbourhood of the targeted steady state, but may be poor approximations in the presence of large deviations from this steady state, as in the case of liquidity trap episodes. By contrast, the non-linear specification allows us to characterize the global dynamics of the model.

Second, Arifovic and Petersen (2015) impose large exogenous and auto-correlated shocks to generate a liquidity trap environment. Correlated shocks may be problematic when it comes to assess whether the observed inflation and output dynamics are purely expectation-driven, or also partly result from these shocks. By contrast, we use “expectational shocks” in the form of news announcements that are unre-

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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).
lated to the fundamentals of the experimental economies. This is another crucial
difference in light of the objectives of our experiment. The reason of this choice is
that we are interested in testing the predictions of learning models, and measuring
the effects of policies on expectations in environments where deflationary pressures
and the emergence of liquidity traps are the result of shifts in expectations. In our
experiment, any fluctuation in aggregate variables and, in particular, the risk of
falling in a liquidity trap are endogenously driven by expectation. Third, Ari-
fovic and Petersen (2015) primarily focus on the role of communication strategies
of central banks near the ZLB, and also touch upon discretionary and exogenous
fiscal shocks, while we test the effects of a policy mix made of preventive cuts in
the interest rate and a rule-based fiscal intervention.

In a first treatment, we consider an aggressive monetary policy, that maintains
the Taylor rule in “normal times”, but preventively cuts the interest rate to the
ZLB when inflation threatens to fall below a given threshold. We compare the
experimental economies under this treatment with a second, policy-mix treatment.
In this second treatment, the aggressive monetary policy is augmented with a fis-
cal switching rule that acts as an inflation-threshold policy: public expenditures
are increased in order to to prevent a fall in inflation below a given threshold
each time the interest rate cut to the ZLB is not enough to revert the decelerat-
ing inflation path. These two policy treatments have a sharp prediction under

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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.

5The related 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 announce-
ments 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, and in line with the focus of our experiment, 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)).
adaptive learning. Moreover, in the model, the effect of changes in public expenditures on private consumption operates solely through the expectation channel. These two treatments are therefore a natural design given the twofold objective of our experiment, that is an empirical test of adaptive learning predictions, and an identification of the expectation channel of fiscal policy.

Our findings can be summarised as follows. Our experimental results confirm the predictions under adaptive learning of the emergence of deflationary paths as a result of severely pessimistic expectations. Without any fiscal intervention, whenever average expected inflation ($\pi^e$) and expected net output ($c^e$) happen to fall (as a result of pessimistic expectational shocks), or initially lie, below the stable manifold of the low inflation state in the ($c^e, \pi^e$)-space, the observed dynamics in the laboratory results in a self-reinforcing deflationary process in which inflation and output decline over time. Conversely, as long as expectations stay above this manifold, the economy converges towards the targeted steady state. When monetary policy is augmented with the fiscal switching rule, in line with the adaptive learning theory, the experimental economies always converge towards the targeted steady state. The fiscal switching rule eliminates the low-inflation steady state and changes the expectational feedback of the model by interrupting downward trends in inflation and output, and therefore avoiding coordination on destabilising deflationary expectations. Even if this latter observation can appear unsurprising at a first glance, a number of LtFEs actually provide experimental evidence that contradicts stability theory under learning, even in the presence of one single, theoretically stable steady state, as this is the case in our policy mix treatment (see, e.g. Hommes et al. (2005)).

Furthermore, our experiment allows us to shed some light on the transitory dynamics along the convergence path towards the target, besides the sole assessment of the final outcome. Even if the inflation-threshold fiscal rule eliminates the possibility of deflationary spirals, we observe that it might lead to almost self-fulfilling equilibria, that are characterized by coordination of inflation expectations
below the targeted level, which makes pessimistic expectational shocks particularly persistent. This results in a prolonged period of low inflation and inflation expectations, and close-to-zero interest rates.

Finally, this policy mix treatment allows us to identify the effects of changes in government expenditures on private consumption through expectations as, in the underlying model of our experiment, the crowding-in or out effect of public expenditures on private consumption operates only through the expectation channel. In our experiment, we estimate larger-than-unity fiscal multipliers at the ZLB.

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 measures the effect of fiscal policy on expectations. Section 6 concludes.

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 specification of the NK model without introducing additional endogenous state variables, while delivering the same functional form of the linearised model around the targeted steady state as in the often used pricing model à la Calvo (1983).6

The key equations describing aggregate dynamics (see Evans et al. (2008) and

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Appendix B for details) are given by

\[ c_t = c^e_{t+1} \left( \frac{\pi^e_{t+1}}{\beta R_t} \right)^{1/\sigma} \]  

\[ \pi_t (\pi_t - 1) = \beta \pi^e_{t+1} (\pi^e_{t+1} - 1) + \frac{\nu}{\alpha \gamma} (c_t + g_t)^{\frac{1+\nu}{\sigma}} + \frac{1-\nu}{\gamma} (c_t + g_t) c_t^{-\sigma}. \]  

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 \( c^e_{t+1} \) and \( \pi^e_{t+1} \) denote respectively expectations of future net output and inflation, \( R_t \) is the nominal gross interest 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 \( \pi_t \), 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 of labour in the production 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 \( Q_t \equiv \pi_t (\pi_t - 1) \). The appropriate root for given \( Q \) is \( \pi \geq 1/2 \), so we need to impose \( Q \geq -1/4 \) to have a meaningful definition of inflation.

For the experimental implementation of the economy described by Eqs. (1)–(2) we follow the parameter values 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 \( \nu \) is set to 21. The parameter \( \gamma \), measuring the cost of deviating from the inflation target under Rotemberg pricing, is related to the price rigidity parameter of Calvo pricing, denoted by \( \phi \), according to \( \gamma = \frac{(\nu-1)\phi}{(1-\phi)(1-\beta \phi)} \). Following Benhabib et al. (2014), we consider a Calvo pricing parameter \( \phi \) 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

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

where $\tilde{R} = 1.0001$ corresponds to the ZLB on the nominal interest rate. 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 $\tilde{\pi}$. We set the reaction coefficients in the interest rate rule to $\phi_c = 2$ and $\phi_y = 0.5$, which are in line with empirical estimates, see, e.g., Taylor (1999), Judd and Rudebusch (1998), Clarida et al. (2000) and Orphanides (2003). This parametrisation ensures local determinacy of the targeted steady state ($\pi^*, c^*$) under RE. However, as emphasised by Benhabib et al. (2001b), “active” Taylor rules imply the existence of a second low-inflation steady state ($\pi_L, c_L$), which is locally indeterminate under RE. Given our parametrisation, there are no steady states other than the target steady state ($\pi^*, c^*$) and the low-inflation steady state ($\pi_L, c_L$).

Fiscal policy is specified as

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

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 $c^* = 0.7454$. Under the aggressive monetary policy

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7We set $\tilde{R} > 1$ so that the corresponding interest rate $\tilde{R} - 1$ is small but positive at the ZLB in order to keep money demand finite, see Appendix B for details.

8The 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 facilitates the experimental implementation due to the nonlinear nature of the model.

9We 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.
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 \((\pi_L, c_L)\) is denoted by a (blue) “L”, while the targeted steady state \((\pi^*, c^*)\) is denoted by a (green) “T”.

![Figure 2](image_url)

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.

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 \(\pi_{t+1}^e\) and \(c_{t+1}^e\), any level of inflation \(\pi_t\) can be achieved by setting \(g_t\) sufficiently high.\(^{10}\)

Therefore the fiscal switching rule is specified as follows: if the inflation threshold \(\tilde{\pi}\) is not achieved under the aggressive monetary policy in Eq. (3), then we

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

\(^{10}\)Moreover, Evans et al. (2008) show that any level of inflation \(\pi_t\) (above 0.5) corresponds to a unique value of \(g_t\) through Eq. (2).
where \( \epsilon \) is a small noise representing control error from the policy maker. 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 quite low, 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 first relaxed in order to stimulate the economy. If the ZLB constraints the effectiveness of monetary policy, aggressive fiscal policy is then 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.\(^{11}\) 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 \( \pi_t \) implicitly defined by Eqs. (1) and (2), together with policy equations (3)–(5), and given expectations \( c_{t+1}^e \) and \( \pi_{t+1}^e \), as follows:

\[
\pi_t = F_\pi(\pi_{t+1}^e, c_{t+1}^e) \tag{6}
\]

\[
c_t = F_c(\pi_{t+1}^e, c_{t+1}^e) \tag{7}
\]

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

\[
\pi_{t+1}^e = \pi_t^e + \delta_t (\pi_{t-1}^e - \pi_t^e) \tag{8}
\]

\[
c_{t+1}^e = c_t^e + \delta_t (c_{t-1}^e - c_t^e) \tag{9}
\]

The term \( \delta_t \) 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 on the equilibrium.\(^{12}\) Rules (8)–(9) are the Perceived Law of Motions (PLMs) that

\(^{12}\)See Evans and Honkapohja (2001) for a formal treatment.
are 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 these 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 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 $\tau$)

\[
\begin{pmatrix}
\frac{d\pi^e}{d\tau} \\
\frac{dc^e}{d\tau}
\end{pmatrix} = \begin{pmatrix}
T_\pi(\pi^e, c^e) \\
T_c(\pi^e, c^e)
\end{pmatrix} - \begin{pmatrix}
\pi^e \\
c^e
\end{pmatrix}
\tag{10}
\]

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

\[
T_\pi(\pi^e, c^e) = EF_\pi(\pi^e_{t+1}, c^e_{t+1}) \tag{11}
\]

\[
T_c(\pi^e, c^e) = EF_c(\pi^e_{t+1}, c^e_{t+1}). \tag{12}
\]

The T-map gives the actual means for $\pi_t$ and $c_t$ when agents have expectations $\pi^e_{t+1}$ and $c^e_{t+1}$. 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 $(\pi^*, c^*)$ is locally stable under learning, while the low-inflation steady state $(\pi_L, c_L)$ is locally unstable under learning, taking the form of a saddle point. In fact, given the parametrisation 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.\textsuperscript{13}

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 \((\pi_L, c_L)\) respectively in forward and 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 \textit{stable} region above the manifold, characterised by convergence to the targeted steady state \((\pi^*, c^*)\), and the \textit{unstable} region below the

\textsuperscript{13}The real eigenvalues at the low inflation steady state are \((0.52, -0.35)\), while the complex eigenvalues at the targeted steady state are \((-0.33 + 0.22i, -0.33 - 0.22i)\).
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 beginning of each session, 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 the 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 indicating how close their past forecasts were to realised values up to period $t - 1$. Fig. 15 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 (with equal probability) for each participant whether she/he 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 of the experiment. The score of subject $i$ in each period for e.g., inflation forecast is determined as $100/(1 + |\pi_{e,i,t} - \pi_t|)$, where $\pi_{e,i,t}$ denotes subject $i$’s forecast for period $t$ and $\pi_t$ 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.$^{14}$

In the instructions, subjects receive a qualitative description of the economy, explaining the mechanisms governing the model equations, but they do not receive quantitative information on the exact values of the structural parameters of the economy. Stated differently, subjects know the signs, positive or negative, of the partial derivatives of the (otherwise unknown) model equations. 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 LtFEs aiming at testing the learnability of RE equilibria, because it keeps the information set of the subjects comparable to the one that agents are assumed to possess under learning (see Duffy (2012) and Hommes (2011)). This assumption seems also more appropriate for the design of an empirical test as the true underlying model of the real-world economy is also unknown, and the aggregate relations between macro variables are only qualitatively understood and agreed upon.

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

$^{14}$Adam (2007), Assenza et al. (2011) and Pfajfar and Zakelj (2015), among others, use an analogous payoff function.
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.  

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.

3.1 Treatments and hypotheses

We implement a $2 \times 2$ experimental design with 4 treatments which differ in the following dimensions. First, we consider two policy regimes (Policy dimension): a policy regime, labelled M, which is characterised by aggressive monetary policy (Eq. (3)) and a fixed amount of public expenditures (Eq. (4)); a second policy regime, labelled 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, labelled 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, labelled 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 $2 \times 2$ matrix describing the four treatments implemented in the experiment is reported in Table 1.

Within the context of the first policy regime labelled “Aggressive Monetary only” (M) in Table 1, we are interested in testing the predictions under adap-

\footnote{During the experiment these constraints were never binding, aside from the cases of liquidity traps in the form of deflationary spirals.}
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 $(\pi^e, \epsilon^e)$-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. At the beginning of the experiment, subjects receive some guidelines of initial values, by being informed in the instructions that in similar economies, inflation and net output have historically been within a certain interval. The mid-points of these ranges typically act as a focal point for subjects’ forecasts in the initial phase of the experiment, which allows us to induce different degrees of initial pessimistic expectations. We can then assess whether the dynamics under learning, depicted in Figure 3, constitutes a good predictor of the ensuing dynamics in the experimental economies.

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 $[0.50, 0.80]$ for net output (given a targeted steady state of about 0.74), so that the mid-point $\{1, 0.65\}$ lies in the “unstable” region. In the other treatment,
labelled “Expectational Shocks” (S) in Table 1, the historical range provided to the subjects in the instructions is [0.95, 1.08] for inflation, and [0.60, 0.80] for net output. In this case, the mid-point {1.015, 0.7} lies in the “stable” region under adaptive learning that theoretically leads to convergence to the targeted equilibrium. 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).\textsuperscript{16} 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. We explicitly tell the 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. the 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 labelled “Additional Fiscal Rule” (F) in Table 1, we are interested in testing the effectiveness of the fiscal switching rule in combating liquidity traps. In particular, we aim at testing 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), and the economy converges to the targeted equilibrium.

We are then interested in characterizing the transitory path, and measuring the effect of fiscal policy on expectations in the experimental economies.

In our experiment, adverse expectations represent the only source of deflationary pressure causing the ZLB to bind, without imposing any large exogenous shock

\textsuperscript{16}Notice 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.
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). By contrast, our experimental design makes the occurrence of liquidity traps and the potential recovery path completely endogenous and dependent on the policy impact on the expectation dynamics. Furthermore, changes in public expenditures $g$ affect net output $c$ only through expectations $\pi^e$ and $c^e$ (see Eq. (1)-(3)). Stated differently, the crowding-in or out effect of fiscal policy on private consumption operates directly through the expectation channel in this model (see further discussion in Section 5). These are appealing features of the chosen underlying economic environment given the objectives of our experiment.

### 3.2 Implementation

The experiment was programmed in Java using the PET software\textsuperscript{17} 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.\textsuperscript{18}

\textsuperscript{17}PET software was developed by AITIA, Budapest, and is available at http://pet.aitia.ai.

\textsuperscript{18}The 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
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.\(^{19}\)

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 \((\pi^*, c^*)\), at least in the long run (see Fig. 4a). In the remaining 5 out of the 7 groups, pessimistic expectations are too severe for monetary policy alone to revert the decelerating inflation path. These economies experience liquidity traps characterised by inflation and output trajectories declining over time. Eventually, inflation expectations hit the lower bounds imposed to ensure well-defined model equations \((-20\%)\). This observation allows us to show the possibility of diverging depressive dynamics in well-identified regions of the phase space of the model. The ensuing wild oscillations are not meant to have any economic interpretation and are therefore not reported in Fig. 4a.\(^{20}\)

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 deflationary spiral in 4 out of the 7 economies.\(^{21}\) In these groups, 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.

\(^{19}\)Experimental economy 6 in treatment FS ended at period 35 due to a server error.

\(^{20}\)For the sake of completeness, we reported the complete time series in Appendix A.

\(^{21}\)In 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
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.
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 cuts the interest rate, and succeeds in stimulating the economy, while in the other two economies, the standard Taylor rule suffices in steering the economy towards the targeted equilibrium.

In treatments FP and FS, we do not observe any deflationary spiral, neither as a result of initial severely pessimistic expectations, nor as a result of adverse expectational shocks (see Figs. 4c – 4d). In 12 out of 14 economies of treatments FP and FS, the fiscal switching rule is activated and government expenditures increase in reaction to low levels of inflation caused by pessimistic expectations, which succeeds in guaranteeing an inflation threshold (see Figs. 13 – 14 in Appendix A). In fact, the fiscal switching rule, by guaranteeing that realised inflation stays close to the threshold \( \tilde{\pi} \), i.e. above the (pessimistic) level of subjects’ expectations, affects the expectational feedback that subjects receive from the experimental environment, and interrupts the deflation trend in their forecasts. To clearly see this, recall that the impact of fiscal policy (i.e. changes in \( g \)) on \( c \) works directly through expectations. The interruption of the negative trend eventually pushes the experimental economies away from the ZLB, leading to convergence to the targeted steady state. This experimental evidence confirms the theoretical results under adaptive learning of Evans et al. (2008) and Benhabib et al. (2014).\textsuperscript{22}

\textsuperscript{22}The 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
However, 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 (Hommes, 2013), and arises as a consequence of the implementation of the fiscal switching policy. The intuition for the emergence of this (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, which prevents further drops in inflation expectations below the threshold, but may not necessarily ensure a rise of expectations above $\tilde{\pi}$. In other words, the fiscal switching rule may not quickly revert expectations. In fact, while fiscal policy ensures a level of inflation around $\tilde{\pi}$, net output adjusts slowly towards equilibrium. As long as realisations and expectations of net output are low enough for the fiscal switching rule to be activated, inflation and inflation expectations remain anchored around $\tilde{\pi}$. Only when net output increases further in the adjustment towards equilibrium will inflation realisations and forecasts raise above $\tilde{\pi}$. Subjects then revise their inflation expectations upward, until convergence to equilibrium. This situation, where inflation and inflation expectations remain below target, combined with low levels of the interest rate, is akin to an almost self-fulfilling liquidity trap steady state characterized by low inflation and interest rate at the ZLB. Therefore, our experiment also sheds light on the transitory path towards the target, and provides evidence that inflation-threshold policies may have the side effect of anchoring expectations to a sub-optimal level. Our results suggest that adverse expectational dynamics can be very persistent and the recovery driven by the policy mix can be slow.

*New Keynesian economies.*
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 \((\pi, c)\)-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 “unstable”, and the region above the stable manifold labelled “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, convergence towards the steady state should always 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 mid-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.\(^{23}\)

We 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

\(^{23}\)
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 and 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, this stimulus is not enough to offset the pessimistic expectations. Deflationary expectations lead to high real interest rates causing eventually both inflation and net output to fall, along the direction of the unstable manifold of the low inflation steady state L.

Fig. 6 refers to treatment MS. In this treatment, the midpoints of the historical ranges for inflation and net output provided to the subjects in the instructions lie in the “stable” region, and we observe that their initial expectations are less pessimistic than in treatment MP. The 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.

However, the expectational shocks in periods 8-10 lead to a shift in expectations towards the bottom left corner of the phase space, i.e. lower expected inflation and net output. Fig. 6b plots the average expectations after the expectational shocks (period 11) for all experimental economies in treatment MS. In line with the predictions under adaptive learning, 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. 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).

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.

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. Most of these 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.

As 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. 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 the 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.

Overall, we find that the predictions of the adaptive learning model in describ-
ing 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 an accurate description of how pessimistic expectations need to be for the economy to follow diverging deflationary dynamics 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 deflationary dynamics. 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).

We now analyse the quantitative effects of fiscal policy in the experimental economies.

5 Measuring the expectation channel of fiscal policy

5.1 Estimation of the impact of fiscal policy at the ZLB in the experiment

We estimate the effect of fiscal policy at the ZLB in the experimental economies. 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, we use data from the experimental economies that fell in a deflationary spiral 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

\[ \mu^*_t = \frac{\bar{y}^F_{t+1} - \bar{y}^M_{t+1}}{\bar{g}^F_{t+1}} , \tag{13} \]

respectively for economies where the binding ZLB is caused by initial severe pessimism \((* = P)\) and expectational shocks \((* = S)\). In Eq. (13), \(\bar{y}^F_{t+1}\) 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 \(t\), \(\bar{y}^M_{t+1}\) denotes the value of output averaged over economies in each treatment \(*\) that experienced a deflationary spiral due to a binding ZLB, and \(\bar{g}^F_t\) 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, 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 may be explained as follows. 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 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. lie 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). Therefore, the magnitude of the multiplier increases when the fiscal policy rule is activated in reaction to accelerating deflationary pressures in the “unstable” region.

We now compare our measurements of the effects of fiscal policy at the ZLB with the related empirical and theoretical literature.

5.2 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 linearised 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.

In the computation of the multiplier for treatment FS, we did not include group 6 from treatment MS in the counterfactual data because the process leading to the fall in the liquidity trap started before, and only got reinforced by the “bad news” announcement (see footnote 21). 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.
than in the case of rational expectations.\textsuperscript{26} 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 as 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 \textit{expectation feedback mechanism}. Therefore, our experiment interestingly complements empirical macro approaches that are confronted to a number of difficulties in quantifying the expectation channel of policies.

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 \textit{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, \textit{policy-invariant} period of time. 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 expectation 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

\textsuperscript{26}However, their estimate are lower than one in both cases.
consumption. In this case, the fiscal multiplier can be larger than one at the ZLB due to the impact of fiscal policy on expectations.

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 are directly elicited from paid human subjects as a test bed for policies against deflationary outcomes. In particular, we use a LtFE to measure the effects of monetary and fiscal policies when deflationary pressures are expectation-driven.

Our results are 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 self-reinforcing pessimistic expectations, even if monetary policy preventively cuts the interest rate when inflation threatens to fall below a certain threshold. On the contrary, the implementation of the fiscal switching rule at the ZLB is successful in avoiding unstable depressive inflation and output paths and guaranteeing convergence to the targeted steady state. Furthermore, we characterize the transitory dynamics along such fiscal interventions. We find that an inflationary-threshold fiscal policy rule may lead to almost self-fulfilling equilibria, which may make expectational shocks very persistent. The resulting convergence path is then characterized by a long transition dynamics, along which inflation and expectations remain at a stable but below-target level, and interest rates remain near the ZLB. Importantly, the LtFE allows us to measure the expectation channel of fiscal policy, and therefore provides a useful complementary tool to test the effectiveness of policies in stylized macroeconomic environments with human subjects. We find values of the fiscal multiplier larger than one. We emphasise that the ability of fiscal stimulus to crowd in private consumption in the experimental economies works
through the expectation feedback mechanism.

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.27 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 future 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 the subjects over a longer horizon. This constitutes an interesting and natural follow-up to the current experiment, which is left for future research.

27See Honkapohja et al. (2013) for a comparison between Euler and infinite horizon learning.
References


Appendix

A Experimental Results

Figs. 11 – 14 report the experimental results for each group in all treatments. In Figs. 11 – 14, 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. 12 and 14 denote the periods in which expectational shocks in the form of “bad news” announcements occur.
Figure 11: Treatment MP
Figure 12: Treatment MS
Figure 13: Treatment FP
Figure 14: 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:

$$\text{Max} \quad E_0 \sum_{t=0}^{\infty} \beta^t U_{t,j} \left( c_{t,j}, \frac{M_{t-1,j}}{P_t}, h_{t,j}, \frac{P_t}{P_{t-1}} - 1 \right)$$

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}^{-1} b_{t-1,j} + \frac{P_{t,j}}{P_t} y_{t,j}$$

(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:

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

(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:

$$y_{t,j} = h_{t,j}^\alpha$$

(16)
with $0 < \alpha < 1$. Each firm $j$ operates under monopolistic competition and faces the following demand curve for its differentiated good $j$:

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

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:

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

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

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

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, 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

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

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

$$\Lambda_t = \kappa_0 + \kappa b_{t-1}$$

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$^28$In order to derive Eq. (19) we used the market clearing condition in the goods market ensuring that $c_t = h_t^e - g_t$. 

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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 $\pi_t$, 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 ($\pi_t$) 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. \( \pi_1^f \) and \( \pi_2^f \), 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 (\( \pi_1 \)), 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 (\( \pi_3^f \) and \( y_3^f \)). When all participants have made their predictions for period 3, inflation (\( \pi_2 \)), 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.

<table>
<thead>
<tr>
<th>Prediction error</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>9</th>
</tr>
</thead>
<tbody>
<tr>
<td>Score</td>
<td>100</td>
<td>50</td>
<td>33.33</td>
<td>25</td>
<td>20</td>
<td>10</td>
</tr>
</tbody>
</table>

**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.
Figure 15: Screenshot
E Additional Experimental Results

Figure 16: Treatment FS, anomalous group.