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MONETARY AND FISCAL POLICY DESIGN AT THE ZERO LOWER BOUND: EVIDENCE FROM THE LAB

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The global economic crisis of 2007–2008 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. (*JEL* E70, C92, D83, D84, E52, E62)

I. INTRODUCTION

The economic experiences in the aftermath of the 2007–2008 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 European Central Bank cut the interest rate to 0.05% in September 2014, and further to 0% in March 2016, and those levels have remained unchanged ever since (see Figure 1).

This scenario characterized 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 macroeconomic theories study liquidity traps using models with rational expectations (REs) that feature multiple equilibria: the liquidity trap is a second low-inflation equilibrium, in addition to the targeted equilibrium, generated by interest rate policies subject to a binding ZLB constraint.[1] RE models with multiple equilibria are then often studied under the assumption of adaptive learning, that is, agents attempt to form RE by learning from past observations (Evans and Honkapohja 2001; Marcet and Sargent 1989), instead of being "endowed" with RE. The criterion of stability under learning is then used as a selection device between the multiple

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1. See, for example, Benhabib, Schmitt-Grohé, and Uribe (2001a, 2001b), Eggertsson and Woodford (2003), Werning (2011), and Mertens and Ravn (2014).

ABBREVIATIONS

LtFE: Learning-to-Forecast Experiment
NK: New Keynesian
REE: RE Equilibrium
REs: Rational Expectations
VAR: Vector Autoregressive
ZLB: Zero Lower Bound

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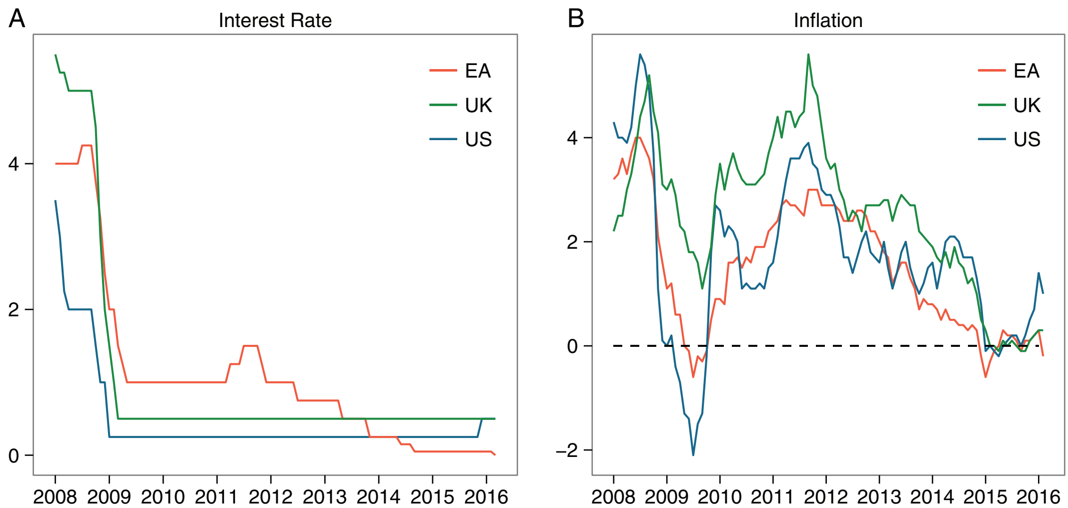
FIGURE 1
Macroeconomic Scenarios in the Euro Area, United States, and United Kingdom



equilibria, based on the view that a plausible RE equilibrium should be potentially reached as the long-run outcome of some learning and updating process—see, for example, Lucas (1978, 1986), Sargent (1993), Grandmont (1998). Along this line, Evans, Guse, and Honkapohja (2008) and Benhabib, Evans, and Honkapohja (2014) study the stability of the targeted equilibrium and the liquidity trap equilibrium under adaptive learning. The authors find that the targeted equilibrium is locally stable, while the low inflation equilibrium is unstable under learning. In practical terms, their results imply that large pessimistic shocks to agents' expectations may result in liquidity traps taking the form of deflationary spirals, along which output and inflation decline over time.[2] Dynamics at the ZLB under learning are therefore fundamentally different from those under RE, which predict convergence to a stable low inflation equilibrium.

In this article, we design a series of laboratory experiments in the same environment as Evans, Guse, and Honkapohja (2008), that is, a nonlinear New Keynesian (NK) model with two equilibria, the target and the low inflation equilibrium. We choose to study this model because it has been widely used to understand macroeconomic dynamics and perform policy analysis in the wake of the Great Recession, both among practitioners and academics. Our lab environment therefore encompasses the main variables that central banks are concerned with, and it reproduces the qualitative relationships between such variables at play in the real world as modeled in modern macroeconomic models.

Our macroeconomic experiment has two main goals. First, we aim to assess whether macroeconomic dynamics at the ZLB can be described by adaptive learning theories. In particular, we want to test whether pessimistic expectations may lead to liquidity traps in the form of deflationary spirals. Second, we aim to measure the impact of monetary and, especially, fiscal policies on expectations and on the resulting dynamics of the economy. More precisely, we aim to assess whether a fiscal policy intervention can help reach the targeted equilibrium and avoid liquidity traps. To rephrase it in the terms of the learning literature aforementioned, we seek to understand how the combination of monetary and fiscal policy influences equilibrium selection in the region near the ZLB.

Our experiment is a learning-to-forecast experiment (LtFE), a design first proposed by Marimon and Sunder (1993) to empirically test theories of expectation formation in a controlled laboratory environment. In the experiment, the

2. Evans, Guse, and Honkapohja (2008) use short-horizon learning based on Euler equations, while Benhabib, Evans, and Honkapohja (2014) use infinite-horizon learning in which agents' decisions are based on forecasts over the entire future. See also Christiano and Eichenbaum (2012) and Mertens and Ravn (2014).

only task of participants is to submit forecasts for inflation and output, and their rewards depend solely on the accuracy of these forecasts. Forecasts are then aggregated and used as inputs in a standard NK model, which describes the dynamics of inflation and output as a function of these forecasts. Optimal firm-households decisions are computerized and computed according to the first-order conditions of the underlying utility/profit maximization problem, conditional to the elicited subjects' expectations. This allows us to reproduce a stylized artificial macroeconomy working along the lines of the workhorse model used by academic and policy institutions, with the important difference that no a priori assumptions are made regarding expectations, which expectations are instead provided by incentivized human subjects.

In recent years, laboratory experiments have become an increasingly important tool to address macroeconomic issues (we refer to Duffy 2016 and Cornand and Heinemann 2014 for a recent and comprehensive overview). In particular, a number of LtFEs have been conducted within NK models, albeit in their simple linearized form, to investigate inflation persistence (Adam 2007), the appropriate design of Taylor rules (Assenza et al. 2018; Pfajfar and Zakelj 2016), disinflationary policies (Cornand and M'baye 2016), and the importance of the expectation channel for macroeconomic stabilization (Kryvtsov and Petersen 2013; Pfajfar and Zakelj 2014); see also Assenza et al. (2014) for a survey of LtFEs in macroeconomics. All those experiments have been particularly useful in assessing the effects of monetary policy on expectations and macroeconomic stabilization. In our experiment, we are also interested in the expectation transmission channel of fiscal policy. Closest to our contribution, Arifovic and Petersen (2017) 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 (2017) use a linear approximation of the NK model to describe the experimental economies, while we use the actual nonlinear specification. This is a critical difference because linearized models provide an accurate description of the dynamics of the model in the vicinity of the targeted equilibrium only, but may be poor approximations in the presence of large deviations from this steady state, as in the case of liquidity trap episodes.[3] By contrast, the nonlinear specification allows us to characterize the global dynamics of the model.

Second, Arifovic and Petersen (2017) impose large exogenous and autocorrelated 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 unrelated to the fundamentals of the experimental economies. The reason of this choice is that we are interested in testing the predictions of macroeconomic 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, liquidity traps can only arise from large pessimistic shocks on expectations.[4]

Third, Arifovic and Petersen (2017) consider both constant and history-dependent inflation targets, investigating how the communication of the history-dependent inflation targets matters near the ZLB, and also touch upon *discretionary* and exogenous fiscal shocks. By contrast, we test the effects of a *policy mix* in which monetary policy may preventively cut the interest rate and fiscal policy is based on a *rule*.

In a first treatment, we consider a so-called "aggressive" monetary policy that maintains a standard interest rate rule in "normal times," but preventively cuts the interest rate to zero as soon as inflation falls below a given low threshold in order to avoid deflation. 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 so-called "fiscal switching" rule that acts in the following way: each time the interest rate cut by the central bank is not enough to revert the decelerating inflation path, fiscal policy

3. The dangers of relying on linear approximations to study liquidity trap dynamics are documented, for example, in Maliar and Maliar (2015), Fernández-Villaverde et al. (2015), Braun, Korber, and Waki (2012) and Aruoba, Cuba-Borda, and Schorfheide (2018).

4. Aruoba, Cuba-Borda, and Schorfheide (2018) estimate a model with fundamental and nonfundamental shocks. Using data from Japan, the authors find that the country experienced the fall to a deflation regime in 1999 due to negative nonfundamental confidence shocks. Schmitt-Grohé and Uribe (2013) also emphasize the role of expectational shocks to explain the joint occurrence of liquidity traps with jobless growth recovery.

is activated and public expenditures are increased so as to prevent a further fall in inflation.[5]

Our findings can be summarized as follows. Our experimental results confirm the predictions of the NK model under adaptive learning, namely, the emergence of deflationary spirals as a result of severely pessimistic expectations. Without any fiscal intervention, whenever average expected inflation and output fall in the region identified as unstable under adaptive learning, we observe a self-reinforcing deflationary process along which inflation and output decline over time in the experimental economies. Conversely, as long as expectations remain in the stable region, the economy converges toward the target of the central bank. Dynamics of the model under learning therefore provides an accurate description of what happens in the laboratory. This result stresses the importance of analyzing the effects of macroeconomic policies in models with learning, and not only under REs.

Under the policy mix, also in line with the adaptive learning theory, the experimental economies always converge toward the targeted equilibrium. The fiscal rule eliminates the low-inflation equilibrium by altering the expectation channel in the model. The fiscal intervention interrupts downward trends in inflation and output, and therefore avoids coordination of the participants on destabilizing pessimistic 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 in other environments, 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 toward the target, besides the sole assessment of the final outcome. Even if the fiscal policy rule eliminates deflationary spirals, we observe that it might lead to *almost self-fulfilling equilibria*, that are characterized by coordination of inflation expectations below the inflation target, 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, the policy mix treatment allows us to identify the effects of changes in government expenditures on expectations and hence output. In our experiment, we estimate larger-than-unity fiscal multipliers at the ZLB.

This article is organized as follows. Section II describes the theoretical framework underlying our experimental economies. Section III provides details on the design of the experiment. Section IV presents the experimental outcomes, while Section V measures the effect of fiscal policy on expectations. Section VI concludes this article.

II. THEORETICAL FRAMEWORK

A. A Nonlinear NK Model

Our experimental economy is based on a standard NK framework with a private sector producing output under monopolistic competition and price frictions. In order to study exact global dynamics in regions that are far from the targeted equilibrium, as in the case of liquidity trap episodes, we follow Evans, Guse, and Honkapohja (2008), Braun, Korber, and Waki (2012), and Benhabib, Evans, and Honkapohja (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 nonlinear specification of the NK model, while delivering the same functional form of the linearized model around the target as in the most often used pricing model *à la* Calvo (1983).[6]

The key equations describing macroeconomic dynamics (see Evans, Guse, and Honkapohja 2008 and Section B of Appendix S1, Supporting Information for details) are given by

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

$$\begin{aligned}\pi_t\left(\pi_t - 1\right) &= \beta\pi^e_{t+1}\left(\pi^e_{t+1} - 1\right) \\ &+ \frac{\upsilon}{\alpha\gamma}\left(c_t + g_t\right)^{\frac{1+''}{\alpha}} \\ &+ \frac{1-\upsilon}{\gamma}\left(c_t + g_t\right)c_t^{-\sigma}.\end{aligned} \tag{2}$$

5. The related literature has proposed other types of monetary and/or fiscal policies aimed to avoid or escape liquidity traps. Some authors proposed policies that make use of announcements and commitment to future policy actions to control agents' expectations and avoid the effects of persistent deflationary outcomes (Eggertsson and Woodford 2003, 2006; Krugman 1998; Woodford 2005). More recently, and in line with the focus of our experiment, a significant strand of the literature analyzed the effectiveness of standard fiscal policies when monetary policy is at the ZLB (Braun, Korber, and Waki 2012; Christiano, Eichenbaum, and Rebelo 2011; Eggertsson 2010; Woodford 2011).

6. See Christiano and Eichenbaum (2012) for details.

Equation (1) describing the dynamics of net output c_t (i.e., output minus government spending) is a standard Euler equation, where c^e_{t+1} and π^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.

Equation (2) is a NK Phillips Curve describing the dynamics of inflation π_t, where g_t is government spending, $\varepsilon > 0$ refers to the marginal disutility of labor, $0 < \alpha < 1$ is the return of labor in the production function, $\gamma > 0$ is the cost of deviating from the inflation target under Rotemberg price adjustment costs, and $\upsilon > 1$ is the elasticity of substitution between differentiated goods. The term $\pi_t(\pi_t - 1)$ in Equation (2) arises from the quadratic form of the adjustment costs. Let $Q_t \equiv \pi_t(\pi_t - 1)$. We need to impose $Q \geq -1/4$ to have a meaningful definition of inflation (i.e., a real number).

For the experimental implementation of the economy described by Equations (1) and (2), we follow the parameter values of Benhabib, Evans, and Honkapohja (2014). The time discount rate is set to $\beta = 0.99$, the labor share is set to $\alpha = 0.7$, parameter υ to 21, and parameter γ to 350 (which corresponds to a probability of not adjusting prices of approximately 0.8 in the Calvo pricing mechanism, see Benhabib, Evans, and Honkapohja 2014 for details). Preferences are assumed to be logarithmic so that $\sigma = \varepsilon = 1$.

B. Monetary and Fiscal Policy

Following Evans, Guse, and Honkapohja (2008), we consider an *aggressive* monetary policy of the form

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

where $R^{\text{ZLB}} = 1.0001$ corresponds to the ZLB on the nominal interest rate.[7] The monetary policy rule (3) is defined as aggressive since, while in "normal" times ($\pi_t \geq \tilde{\pi}$), it follows a standard interest rate rule, it preventively cuts the nominal interest rate to the ZLB each time inflation drops below a given threshold $\tilde{\pi}$.[8] We set the reaction coefficients in the interest rate rule to $\phi_\pi = 2$ and $\phi_y = 0.5$, which are in line with empirical estimates, see, for example, Taylor (1999), Judd and Rudebusch (1998), Clarida, Gali, and Gertler (2000), and Orphanides (2003). This parametrization ensures the local determinacy of the targeted equilibrium (π^*, c^*) under RE, and local stability of the equilibrium under learning. However, as emphasized by Benhabib, Schmitt-Grohé, and Uribe (2001b), this type of interest rate rules implies the existence of a second low-inflation steady state (π_L, c_L), which is locally indeterminate under RE, and unstable under learning. Given our parametrization, there are no deterministic steady states other than the target one (π^*, c^*) and the low inflation on (π_L, c_L). The two equilibria of the model are depicted in Figure 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."

In the absence of policy mix, fiscal policy is specified as

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

where $\bar{g}$ is fixed. As in Evans, Guse, and Honkapohja (2008), we set $\pi^* = 1.05$ which implies a net output equilibrium value of $c^* = 0.7454$.[9] Under the aggressive monetary policy in Equation (3), the low-inflation steady state is given by $(\pi_L, c_L) = (0.99, 0.7428)$.

We also consider the fiscal policy design proposed by Evans, Guse, and Honkapohja (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 maintain inflation above the worrisome threshold $\tilde{\pi}$. Indeed, Evans, Guse, and Honkapohja (2008) show that, in the model defined by Equation (1) and (2), given expectations π^e_{t+1} and c^e_{t+1}, any level of inflation π_t can be achieved by setting g_t sufficiently high. The idea behind this monetary-fiscal policy mix is the following. If the

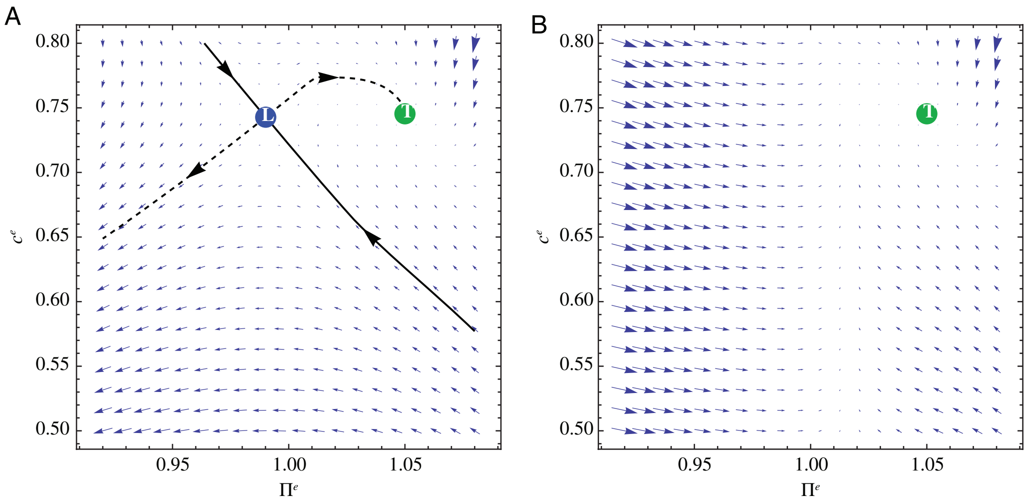
7. We set $R^{\text{ZLB}} > 1$ so as to keep the corresponding interest rate $R^{\text{ZLB}} - 1$ small but positive at the ZLB and the money demand finite, see Section B of Appendix S1, Supporting Information for details.

8. The main results in the following would also hold in the case of a contemporaneous Taylor rule as emphasized by Evans, Guse, and Honkapohja (2008). Using a forward-looking specification for the Taylor rule facilitates the experimental implementation due to the nonlinear nature of the model.

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

FIGURE 2

Panel (A): Multiple Equilibria and Learning Dynamics with Coexistence of Low Inflation Equilibrium L and Targeted Equilibrium T under Aggressive Monetary Policy. Panel (B): Unique Targeted Equilibrium T and Learning Dynamics under Policy Mix



inflation target is not achieved under a standard interest rate rule, monetary policy first intervenes to stimulate the economy by setting the interest rate to the ZLB. If the ZLB constrains monetary policy in a way that prevents inflation from remaining above the critical threshold $\tilde{\pi}$, fiscal policy is then activated.

Specifically, the fiscal switching rule works as follows: if the inflation threshold $\tilde{\pi}$ is not achieved under the aggressive monetary policy in Equation (3), then we

(5)

$$\begin{cases} \text{(i) compute the interest rate } R_t^{\tilde{\pi}} \text{ consistent with} \\ \quad \text{Eqs. (1)} - \text{(2) and } \pi_t = \tilde{\pi} \\ \text{(ii) set } R_t = \max\left[R_t^{\tilde{\pi}}, R^{\text{ZLB}}\right] \\ \text{(iii) if } R_t = R^{\text{ZLB}} > R_t^{\tilde{\pi}}, \text{then } g_t \text{ is adjusted} \\ \quad \text{upward such that } \pi_t = \tilde{\pi} \quad (+") \end{cases}$$

where ε is a small noise representing control error from the policy maker. In other words, if the interest rate required to attain the inflation threshold (Step (i)) is lower than the ZLB (Step (ii)), then fiscal policy is activated (Step (iii)) in combination with zero interest rates.

As shown by Evans, Guse, and Honkapohja (2008), choosing $\pi_L < \tilde{\pi} < \pi^*$ eliminates the second, low inflation equilibrium and ensures that the targeted equilibrium is unique. 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 (Equation (3)) and fiscal policy (Equation (5)) is illustrated in Figure 2B.

In our setting, fiscal policy takes the form of changes in government spending. We remark that we do not impose a bound on government spending necessary to generate inflation. Public expenditures are financed by a passive fiscal policy as in Leeper (1991). Therefore, 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 Section B of Appendix S1, Supporting Information and Evans, Guse, and Honkapohja 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 and interest rate gradually returns to their equilibrium levels. As shown in Evans, Guse, and Honkapohja (2008), the earlier fiscal policy reacts to adverse expectations, the lower the debt build-up.

C. Stability under Learning and Equilibrium Selection

In this section, we summarize the nonlinear NK model dynamics under adaptive learning, described in detail in Evans, Guse, and Honkapohja (2008). In Section IV, we then evaluate whether adaptive learning explains the observed dynamics in the laboratory experiments.

In the presence of multiple equilibria under RE, stability under adaptive learning, or E-stability, has been commonly used to select among multiple RE equilibria. E-stability amounts to assessing the dynamic stability of the model when agents, instead of using REs, form their forecasts using simple econometric models, such as recursive least squares or constant gain estimation (Evans and Honkapohja 2001; Marcet and Sargent 1989). If their forecasts (π^e, c^e), together with the variables of the model (π_t, c_t) converge to a given RE equilibrium (REE) (π^*, c^*) when $t \to \infty$, this equilibrium is said to be stable under learning. The main idea is that equilibria that yield unstable dynamics under learning should be dismissed because they cannot be considered as empirically plausible.[10] Hence, REs and adaptive learning can be viewed as complementary approaches: REs allow one to identify the potential equilibria of the model in the long run, and adaptive learning allows one to test which one is actually plausible based on whether agents are able to learn it over time.

To make this argument formally, it is useful to write the equilibrium law of motion of c_t and π_t in any period t, that is implicitly defined by Equations (1) and (2), together with policy Equations (3)–(5), and given any expectations c^e_{t+1} and π^e_{t+1}:

$$\pi_t = F_\pi \left(\pi^e_{t+1}, c^e_{t+1}\right) \tag{6}$$

$$c_t = F_c \left(\pi^e_{t+1}, c^e_{t+1}\right). \tag{7}$$

Following Evans, Guse, and Honkapohja (2008), Mertens and Ravn (2014), and Benhabib, Evans, and Honkapohja (2014), we consider that agents form adaptive expectations as follows[11]:

$$\pi^e_{t+1} = \pi^e_t + \delta_t \left(\pi_{t-1} - \pi^e_t\right) \tag{8}$$

$$c^e_{t+1} = c^e_t + \delta_t \left(c_{t-1} - c^e_t\right). \tag{9}$$

The term δ_t refers to the gain sequence. Under least squares learning, the gain sequence is $\delta_t = t^{-1}$ (i.e., the gain is decreasing) whereas, under constant gain learning, it is set to $\delta_t = \delta$, $0 < \delta < 1$ (i.e., the gain is a small positive constant). Notice that the limit case $\delta = 1$ corresponds to naive or myopic expectations ($\pi^e_{t+1} = \pi_{t-1}$). The theoretical stability results for the model under learning are obtained using the learning rules (8)–(9). Equilibria that can be reached via simple learning rules, such as Equations (8) and (9), constitute more plausible model predictions than equilibria that would require more sophisticated forecasting rules. An important goal of this article is to test experimentally whether this adaptive learning model is a good predictor of the emergence of liquidity traps when expectations are provided directly by human subjects.

Formally, E-stability of an REE is determined by the Jacobian matrix of the so-called T-map, that is, the mapping from the PLM to the corresponding actual law of motion, evaluated at this equilibrium. The REE is said to be E-stable if the differential equation (in notional time τ)

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

is asymptotically stable in the vicinity of the steady state (π, c), where $T(.)$ is the T-map defined as (see Evans et al. 2008, 1445):

$$T_\pi(\pi^e, c^e) = \mathrm{E}F_\pi \left(\pi^e_{t+1}, c^e_{t+1}\right) \tag{11}$$

$$T_c(\pi^e, c^e) = \mathrm{E}F_c \left(\pi^e_{t+1}, c^e_{t+1}\right). \tag{12}$$

The T-map gives the actual means of π_t and c_t when agents have expectations π^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. Under the aggressive monetary policy regime of Equation (3) and the constant fiscal policy rule of Equation (4), Evans, Guse, and Honkapohja (2008) show that the targeted equilibrium (π^*, c^*) is locally stable under learning, while the low-inflation equilibrium (π_L, c_L) is locally unstable under learning, taking the form of a saddle point.[12]

10. See, for example, McCallum (2003), Adam (2003), Lettau and Van Zandt (2003) among others, and Christiano and Eichenbaum (2012) for an application to liquidity trap contexts. For a comprehensive treatment of the adaptive learning literature and the details of the derivations below, we refer the reader to Evans and Honkapohja (2001).

11. Within this model, this form of expectations is called "steady-state learning" because it has the same form as the simplest equilibrium within this model, that is, a simple intercept. This simplest equilibrium form is called the minimum state variable (MSV) solution. Hence, Rules (8) and (9) are called the perceived law of motions (PLMs) that are consistent with the MSV solution.

12. Given the parametrization of our experimental economy, the eigenvalues computed at the low-inflation equilibrium are real and of different signs (0.52, −0.35), while for the targeted equilibrium we have complex eigenvalues with negative real parts (−0.33 + 0.22i, −0.33 −0.22i).

It is particularly revealing to provide a graphical representation of the dynamics of the model under learning. To this aim, Figure 2A gives the corresponding phase diagram. The solid black and the dashed black curves depict, respectively, the stable and unstable manifold of the saddle low-inflation equilibrium (blue "L").[13] The E-stability analysis shows that the targeted equilibrium is only *locally* stable, that is, there exist regions in the phase space (π^e, c^e) where expectations formed by the simple learning rules (8)–(9) would not converge to the targeted equilibrium (π^*, c^*). This is due to the saddle property of the second, low-inflation equilibrium. The stable manifold associated with this saddle point (i.e., the solid black line) creates a division of the phase space into two regions: the *stable* region above the manifold, where expectations converge to the targeted equilibrium (π^*, c^*), and the *unstable* region below the manifold where expectations, and actual inflation and output, spiral down over time. This analysis under learning shows how large pessimistic shocks may push expectations into this unstable region, which could result in liquidity traps taking the form of self-reinforcing deflationary spirals and depressive dynamics.

By contrast, under the policy mix regime, that is, when the aggressive monetary policy is augmented with the fiscal switching rule described in Equation (5), the targeted equilibrium is *globally* stable under learning, as discussed in Evans, Guse, and Honkapohja (2008). As shown in Figure 2B, diverging deflationary spirals are eliminated, and all expectations (π^e, c^e) converge to the (π^*, c^*). In the experiment, we are interested in empirically testing these predictions of the learning model in describing the occurrence or avoidance of liquidity traps.

III. EXPERIMENTAL DESIGN

A. *Procedures and Environment*

The experiment is an LtFE with a group design and within session randomization. At the beginning of each session, participants are divided into groups (experimental economies) of six and they only interact with people in their experimental economy. Subjects are assigned the role of advisors for statistical institutes and their only task is to make two-period-ahead forecasts of inflation and net output for 50 periods.[14] Average forecasts are then used as inputs into the model (1)–(3), with fiscal policy defined by either (4) or (5) (see below for a description of treatments), in order to compute the realizations of inflation and net output.

In each period t, when making forecasts for period $t+1$, the information set visualized on the subjects' screens includes all realizations 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 realized values up to period $t-1$. Supporting Information Figure 14 in Section D of Appendix S1 shows the computer interface as visualized by the 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 rationale for this choice is to avoid subjects focusing on the forecast of one variable rather than the other.[15] 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, for example, inflation forecast is determined as $100/\left(1+|\pi^e_{i,t}-\pi_t|\right)$, where $\pi^e_{i,t}$ denotes subject i's forecast for period t and π_t is the realized value of inflation in period t (the score is computed in an analogous way for net output). Therefore, subjects' payment decreases with the (absolute) distance of realizations from their forecasts.[16]

In the instructions, subjects receive a *qualitative* description of the economy, explaining the mechanisms governing the model equations,

13. On a technical note, the stable and unstable manifolds have been obtained as numerical approximations of learning dynamics converging to the low-inflation equilibrium (π_L, c_L) in, respectively, forward and backward time.

14. We assign subjects the role of advisors for statistical research bureaus in order to emphasize that their only task during the experiment is to make forecasts. However, our goal is not to get inference on how professionals form expectations, but rather on how common people make predictions. In fact, the relevant forecasts for the model underlying our experimental economies are those of firm-households making consumption, working, and pricing decisions as a function of their forecasts. Optimal decisions conditional to the elicited beliefs are computed by a computer program.

15. Subjects could have a greater ease in forecasting, for example, inflation when the experimental economies remain in a low but stable inflation regime (see Section IV.A). Given our incentive mechanism, subjects should pay equal attention to both forecasts throughout the experiment.

16. Adam (2007), Assenza et al. (2018), and Pfajfar and Zakelj (2016), among others, use an analogous payoff function.

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, for example, that there is a positive relation between realized 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 to test the predictions of macro models under learning dynamics, because it keeps the information set of the subjects comparable to the one that agents are assumed to possess under learning (Duffy 2016; Hommes 2011). This assumption seems also more appropriate for the design of an empirical test of policy effectiveness as the true underlying model of the real-world economy is also unknown, and the aggregate relations between macrovariables are only qualitatively understood and agreed upon. Moreover, several experimental works, albeit in simpler linear environments, have shown that, even if subjects do not know the exact equations of the economy, they can learn to coordinate on RE equilibria (see Hommes 2011). Furthermore, experiments in a similar vein but in a simpler linear environment have been run providing subjects with the equations of the data generating process in the experiment (see, e.g., Mokhtarzadeh and Petersen 2017). The dynamics observed in such experiments are similar to those observed in our experiment.

In order to prevent exact coordination of subjects on the deterministic equilibria and, hence perfect forecasts, we buffet the economy with small additive white noise shocks to Equations (1) and (2) with a standard deviation of 0.0025.[17] Subjects are informed that realizations inflation and net output are affected by these small random shocks.

The complete instructions can be found in Section C of Appendix S1, Supporting Information. As noticed in Section II, 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 II, 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 only in case their forecasts were outside the allowed range.[18]

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. Moreover, the scaled-up values are less likely to suffer from the severe rounding that might occur if the forecasts were to be expressed as decimals.

B. Treatments and Hypotheses

We implement a 2×2 experimental design with four treatments which differ in the following dimensions (see Table 1). First, we consider two policy regimes (*Policy* dimension): a policy regime, labeled M, which is characterized by aggressive monetary policy (Equation (3)) and a fixed amount of public expenditures (Equation (4)); and a second policy regime, the policy mix, labeled F, which is characterized by the same aggressive monetary policy augmented with the fiscal switching rule (Equation (5)).

The second dimension concerns the source of pessimistic expectations that may generate liquidity traps in the model (*Expectations* dimension). In one scenario, labeled 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 S, pessimistic expectational shocks are induced later in the experiment, that is, when the experimental economies are already moving along a converging path toward the target equilibrium (see below for details). The 2×2 matrix

17. In stable treatments, we clearly observe that these shocks do not hinder convergence to the target equilibrium. In fact, such shocks alone cannot move experimental economies from the stable to the unstable region. Only large pessimistic shifts in expectations, following, for example, bad news shocks, can. Symmetrically, these shocks cannot alone revert unstable dynamics and push back the experimental economies in the stable region. Only large optimistic expectational shocks could, but we do not observe any.

18. During the experiment, these constraints were never binding when the economies were in "normal times," that is, on a converging path toward the target steady state. The only cases in which these constraints bound were 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. We interpret this scenario as laboratory evidence of the possibility of subjects' coordination on paths leading to deflationary spirals.

TABLE 1
Summary of the Four Treatments

	Expectations	
	Severe initial *Pessimism* (P)	**Expectational *Shock* (S)**
	Announced initial intervals	
	π: [0.92, 1.08] **c: [0.50, 0.80]**	**π: [0.95, 1.08]** **c: [0.60, 0.80]**
	"Bad news" shocks	
	None	**In periods 8–10**
Policy		
Monetary policy only (M)	MP	MS
Additional *Fiscal* rule (F)	FP	FS

describing the four treatments implemented in the experiment is reported in Table 1.

Within the context of the first policy regime labeled "Monetary policy only" (M) in Table 1, we are interested in testing the predictions under adaptive learning about the occurrence and characteristics of liquidity trap episodes, summarized in the following hypothesis:

> **Hypothesis:** *Under the policy regime M (described by Equations (3) and (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 pessimistic 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 low expectations about future inflation and net output, the economy is in the "unstable" region where pessimistic expectations are self-reinforcing, we try to affect the starting level of pessimism in the experimental economy in the following way. At the beginning of the experiment, subjects receive some guidelines about initial values of inflation and net output, by being informed in the instructions that in similar economies, inflation and net output have historically been within a given interval. The midpoints of these intervals typically act as an average 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 2A, constitutes a good predictor of the ensuing dynamics in the experimental economies.

In one treatment, denoted as "severe initial Pessimism" (P) in Table 1, we induce an initial situation of severe pessimism by providing the historical range of [0.92, 1.08] for inflation (given a target of 1.05) and [0.50, 0.80] for net output (given a target equilibrium value of about 0.74). In this case, the midpoint $\{1, 0.65\}$ lies in the "unstable" region. In another treatment, labeled "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 midpoint $\{1.015, 0.7\}$ lies in the "stable" region under adaptive learning that theoretically leads to convergence to the targeted equilibrium.

Pessimism in Treatment S is induced by expectational shocks in Periods 8–10: some "bad news" pop up on the participants' screens in those periods in the form of newspaper reports with experts' opinions about future economic conditions (see Experimental Instructions in Section C of Appendix S1, Supporting Information for details). The bad news announcements are repeatedly given in Periods 8–10 due to the two-period-ahead nature of the forecasting task. 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 realizations 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.[19]

19. Given that the bad news shocks are meant to shift expectations when the economy is on a converging path to the target equilibrium, such news are not in line with recently observed history. A way to think about these shocks is as "sunspots," as subjects are informed they do not influence the dynamics of inflation and output. Subjects react to the news if they believe that other subjects may react to them by lowering their expectations, which would in turn impact the actual realizations of inflation and output due to the self-referential nature of the system.

Notice that, even though treatments with *Severe Pessimism* (MP and FP) do not involve any bad news shocks, subjects in those treatments were informed about the possibility of news announcements, so that the experimental instructions are the same for all treatments, with the exception of the historical ranges for inflation and net output.

In the context of the second policy regime labeled "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 to test the following hypothesis:

> **Hypothesis:** *Under the policy regime F (described by Equations (3) and (5)), liquidity traps in the form of deflationary spirals are prevented, whether induced by initial severe pessimism (treatment FP) or by pessimistic 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, pessimistic 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 SD 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 liquidity traps arise as a result of a temporary negative exogenous preference shocks, but that the economy always ends up reverting back to the targeted equilibrium (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, in the sense that those dynamics are only dependent on the impact of policies on expectations. Furthermore, the only *direct* effect of changes in public expenditures (g) on net output (c) works through expectations π^e and c^e (see Equations (1)–(3)). Stated differently, the so-called "crowding-in" or "crowding-out" effect of fiscal policy on private consumption, which determines whether fiscal expansions are helpful in a recession, operates *directly* through expectations (see further discussion in Section V). This observation highlights the importance of the expectation channel of fiscal policy as well, while the macroeconomic literature often focuses on the role of expectations for monetary policy. These are appealing features of the chosen underlying economic environment given the objectives of our experiment.

C. Implementation

The experiment was programmed in Java and it was conducted at the CREED laboratory at the University of Amsterdam. A total of 168 subjects recruited from the CREED subject pool took part in the experiment (seven experimental economies of six subjects each for each of the four treatments). 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 2 hours and participants earned on average 21.1 euros. The series of small independent and identically distributed shocks buffeting the experimental economies were the same for all groups.[20]

IV. EXPERIMENTAL RESULTS

A. Overview of the Results

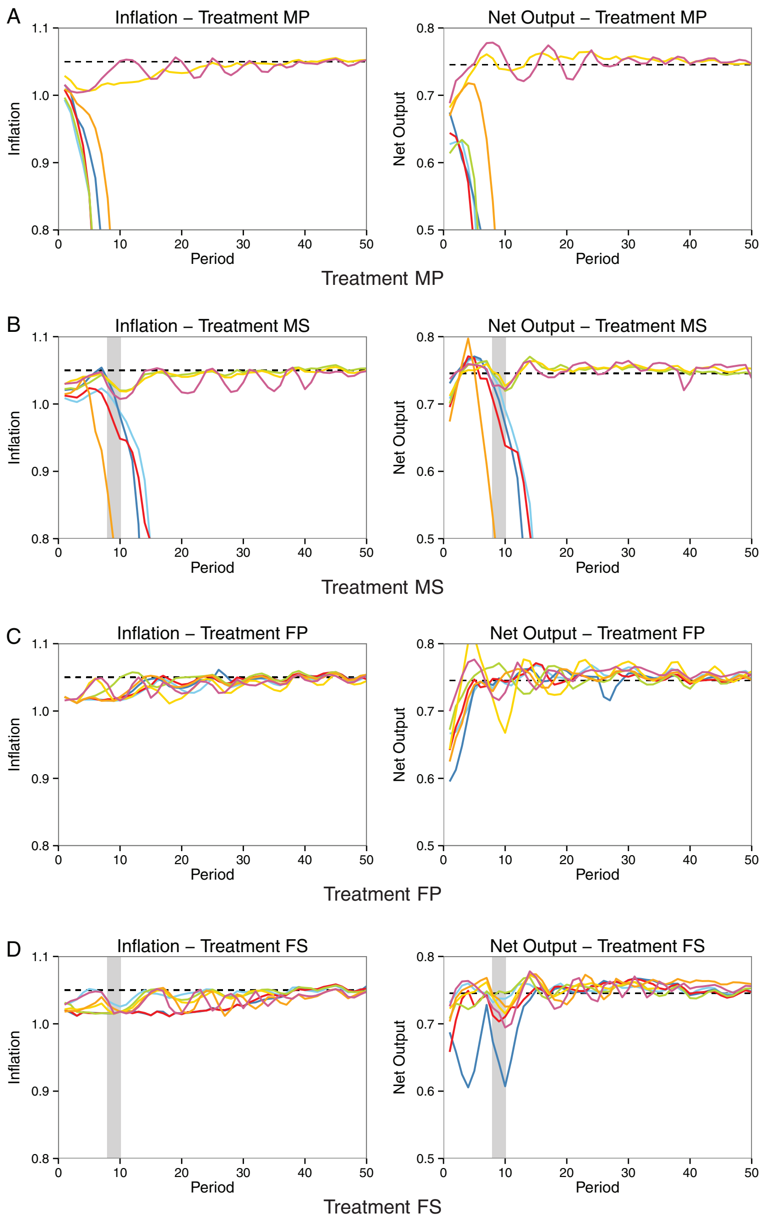
An overview of the experimental results is reported in Figure 3 (the data for each group including interest rate, government expenditure, and expectations dynamics are reported in Section A of Appendix S1, Supporting Information). Each line corresponds to realized inflation (left panels) and net output (right panels) in one experimental economy (seven economies per treatment), tracked over all 50 periods of the experiment.[21]

In treatment MP, initial pessimistic expectations lead to realized 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 two out of the

20. 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 to severe misunderstandings of one subject who behaved very strangely and made nonsensible predictions, systematically far away from actual realizations (thereby also losing a lot of money). The results for this group are reported for completeness in Section E of Appendix S1, Supporting Information.

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

FIGURE 3
Overview of Experimental Results of the Four Treatments, Seven Groups Each



Notes: Left panels: realized inflation. Right panels: realized net output. Dashed lines depict targeted equilibrium levels. Shaded areas indicate the periods of the "bad news" shocks.

seven economies, this policy measure is sufficient to avoid deflation and deep recessions, by preventing expectations from falling further into the unstable region, and granting convergence to the targeted steady state (π^*, c^*), at least in the long run (see Figure 3A). In the remaining five out of the seven groups, pessimistic expectations are too severe for monetary policy alone to revert the decelerating inflation and output path. These economies experience liquidity traps characterized by deflation 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 highlight the possibility of diverging depressive dynamics in well-identified regions of the model. The ensuing wild oscillations are not meant to have any economic interpretation and are therefore not reported in Figure 3A.[22]

In treatment MS, all economies start converging to the targeted equilibrium in the initial phases of the experiment, before the first expectational shock in Period 8. However, the "bad news" occurring in Periods 8–10 (shaded areas in Figure 3B) push the subjects' forecasts into the unstable region, causing a deflationary spiral, in four out of the seven economies.[23] 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 realizations of 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 pessimistic 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. In the other two economies, the standard Taylor rule suffices in steering the economy toward the targeted equilibrium despite the expectational shocks.

In treatments with the policy mix, we do not observe any deflationary spiral, neither as a result of initial severely pessimistic expectations—treatment FP—nor as a result of pessimistic shocks—treatment FS (see Figures 3C and 3D). In 12 out of those 14 economies, 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 Supporting Information Figures 12 and 13 in Section A of Appendix S1). In fact, the fiscal switching rule, by guaranteeing that realized inflation stays close to the threshold $\tilde{\pi}$, that is, above the (pessimistic) level of subjects' expectations, affects the *expectational feedback* that subjects receive from the experimental environment,[24] which puts an end to 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 π^e and c^e. 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, Guse, and Honkapohja (2008) and Benhabib, Evans, and Honkapohja (2014).

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 and 5 in treatment FP, and Groups 5–7 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, and 6 in treatment FP, and Groups 2–4 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.

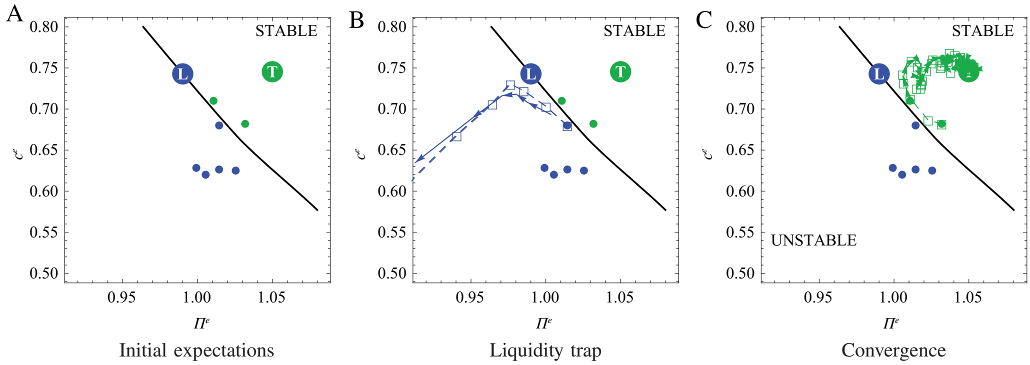
The intuition for the emergence of this (temporary) state is the following. Any downward trend in inflation and expectations below the threshold $\tilde{\pi}$ is interrupted by stabilizing inflation around $\tilde{\pi}$. Therefore, the inflation level $\tilde{\pi}$ may act as an anchor for subjects' 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 toward equilibrium. As long as realizations and expectations of net output are low enough for the fiscal switching rule to

22. For the sake of completeness, we reported the complete time series in Section A of Appendix S1, Supporting Information.

23. 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 it is reinforced by the bad news announcement.

24. The importance of the nature of the expectational feedback, that is, the way realizations of variables react to subjects' expectations, has been recognized in earlier experimental works, see, for example, Nagel (1995), Heemeijer et al. (2009), Fehr and Tyran (2008), among others. What is key here is that subjects do not forecast a random, exogenous process, but the system is self-referential: realizations are affected by expectations, and vice versa. See also Assenza et al. (2018) for an experimental investigation of the impact of alternative monetary policies on the expectations feedback system in New Keynesian economies.

FIGURE 4
Treatment MP



be activated, inflation and inflation expectations remain anchored around $\tilde{\pi}$. In this sense, the fiscal rule introduces strategic complementarity in the system, leading to almost self-fulfilling equilibria in which expected and realized inflation (almost) coincide. Only when net output increases further in the adjustment toward equilibrium will inflation realizations and forecasts rise 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 toward the target, and provides evidence that inflation-threshold policies may have the side effect of anchoring expectations to a suboptimal level. Our results suggest that pessimism can be very persistent and the recovery driven by the policy mix can be slow.

B. *Learning Model Predictions*

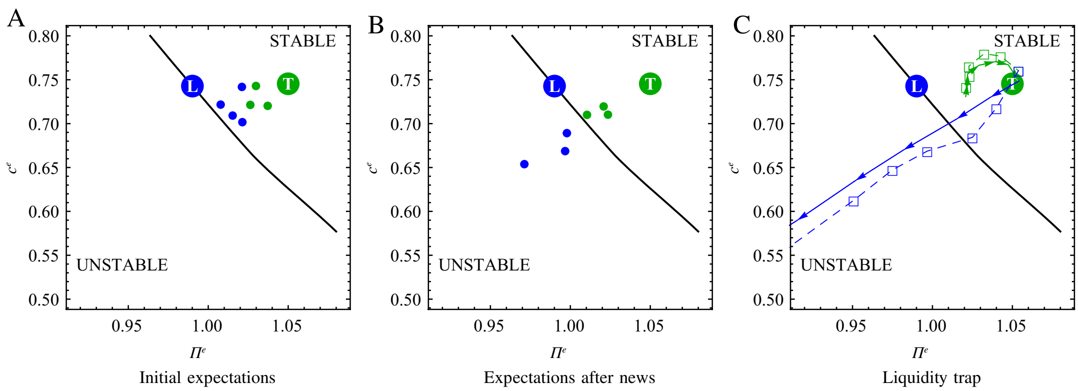
We now turn to the assessment of the learning model's predictions summarized in Hypotheses 1 and 2 in light of our experimental evidence. Figures 4–6 display experimental data in the (π, c)-space, together with the stable manifold of the low-inflation equilibrium that demarcates the stable and the unstable regions of the model under learning (see Section II.C). The corresponding regions are labeled "stable" and "unstable." According to Hypothesis 1, expectations which are pessimistic enough to fall in the "unstable" region lead to deflationary spirals in treatments MP and MS. According to Hypothesis 2, convergence toward the target should always occur in treatments FP and FS.

Recall that 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 midpoints of the intervals lie in the "unstable" region. Figure 4A plots subjects' average expectations in Period 2 for the seven experimental economies in treatment MP.[25] 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 into a liquidity trap, while all economies in which expectations are less pessimistic and lie instead in the "stable" region converge to the target.

In addition, Figure 4B provides a typical example of deflationary dynamics (Group 6) and Figure 4C a typical example of converging dynamics (Group 5). In Figures 4B and 4C, solid lines refer to realizations of inflation and net output and dashed lines depict the dynamics of average subjects' expectations. Figure 4B 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.

25. We plot average expectations in Period 2 (for Period 3) because this is the first period in which subjects observe realized 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 MS



However, this stimulus is not enough to offset the pessimistic expectations, which eventually cause both inflation and net output to spiral downward. On a technical note, the downward spiral follows the direction of the unstable manifold of the low inflation steady state L (see Figure 2A).

Figure 5 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. We indeed 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 Figure 5A, and all groups start converging to the targeted equilibrium in the first periods of the experiment. However, the expectational shocks in Periods 8–10 lead to a shift in expectations toward the bottom left corner of the phase space, that is, lower expected inflation and net output. Figure 5B 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 (characterized again by blue points) fall into a liquidity trap, while all economies in which expectations remain in the "stable" region (characterized again by green points) eventually recover and converge to the targeted equilibrium.[26]

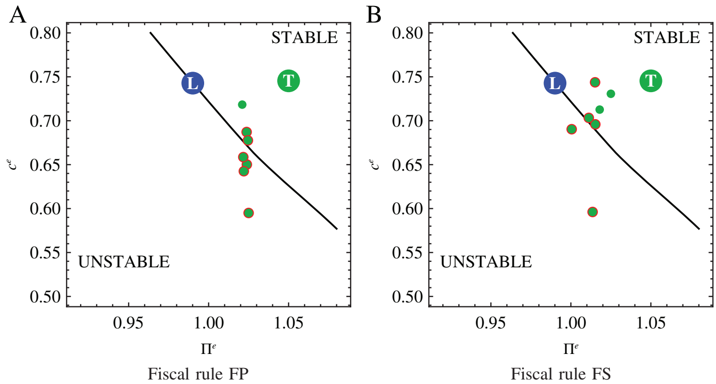
26. As mentioned above, in one experimental economy (Group 6), the fall in the liquidity trap starts before the expectational shocks and thus, by Period 11, expectations are beyond the boundaries of Figure 5B, explaining why we only observe six instead of seven points.

Figure 5C 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 fall along a self-reinforcing spiral causing deflationary outcomes (blue solid line).

Figure 6 refers to treatments FP and FS, in which the fiscal switching policy rule is implemented. Figure 6A displays the average initial expectations in all economies of treatment FP, characterized by initial severe pessimism, while Figure 6B 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 equilibrium. 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 the fiscal rule.

Figure 7 compares the experimental data with the dynamics of the model under 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

FIGURE 6
Treatments FP (Left) and FS (Right)



dynamics observed in the experiment (blue and green squares). Figure 7A refers to the example of a liquidity trap observed in treatment MP and previously described in Figure 4B; Figure 7B refers to the example of convergence to the target in treatment MP depicted in Figure 4C, and Figure 7C corresponds to the example of a liquidity trap caused by "bad news" announcements in treatment MS reported in Figure 5C.

Overall, we find that the observed dynamics are fundamentally different from those predicted under RE, that is, a continuum of equilibrium paths converging to the low-inflation steady states, and that predictions of the adaptive learning model in describing the occurrence of liquidity trap are supported by the experimental results.

A critical reader might find this result unsurprising given the information set of the subjects and their experimental task. However, quite an extensive number of LtFEs have shown that laboratory evidence may contradict the predictions of adaptive learning, even in univariate models with one single equilibrium that is stable under learning (see, e.g., Hommes et al. 2005; see also Bao and Duffy 2016 for an experimental test of different learning mechanisms). As the underlying model of our experiment is more complicated, displaying two variables and two RE equilibria, nothing could grant beforehand that adaptive learning would well describe the observed dynamics in the lab.

Next, we analyze the quantitative effects of fiscal policy in the experimental economies.

V. MEASURING THE EXPECTATION CHANNEL OF FISCAL POLICY

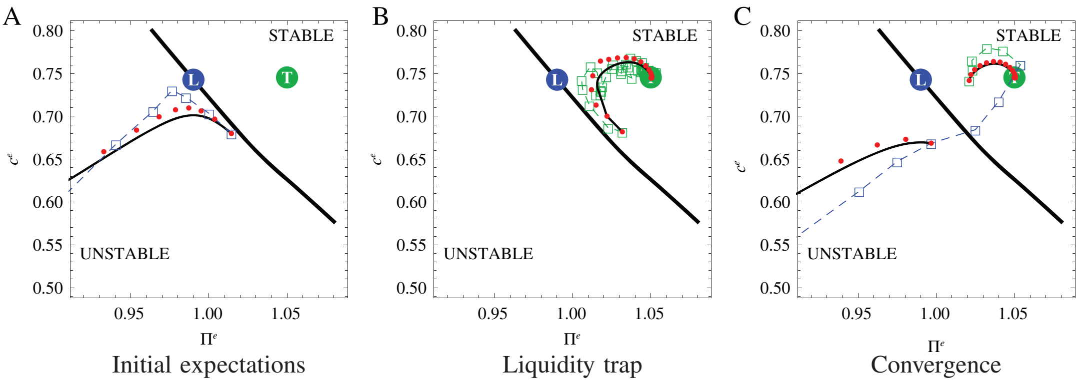
A. *Estimation of the Impact of Fiscal Policy at the ZLB in the Experiment*

We estimate the effect of fiscal policy at the ZLB in the experimental economies of treatments FP and FS in which the fiscal switching rule is activated. In the related literature, the estimation of the fiscal multiplier requires a counterfactual history in which fiscal policy is different from the baseline policy. This is usually obtained with either simulated DSGE models or estimated structural vector autoregressive (VAR) models that isolate the effects of nonsystematic fiscal policy changes on output (see Ramey 2011 for a survey and discussion of the two methods). However, none of the two methods is directly transportable in the lab. Indeed, replicating the same experimental economy with the same subjects while changing fiscal policy would result in nonindependent observations. On the other hand, the VAR approach studies fiscal shocks that are not responses to the current state of the economy, while we seek to estimate the cumulative multiplier over time, that is, the output responses to the whole countercyclical fiscal policy in the experiment.

Hence, we use the experimental economies that fell into a deflationary spiral due to a binding ZLB in treatments MP and MS as counterfactual observations. Besides ensuring independent observations, the two scenarios are subject to the same expectational shocks (either triggered by initial pessimism or the display of bad news). In addition, we use only the first three periods

FIGURE 7

Simulated Expectations Dynamics under Decreasing Gain (Solid Black Lines) and Naive Expectations (i.e., Constant Gain $\delta = 1$, Red Points), Experimental Data Converging to the Targeted Steady State (Green Squares), and Deflationary Spirals (Blue Squares)



in the aftermath of those shocks to estimate the multiplier to circumvent the issue of subsequent histories that may strongly differ, especially once an economy is thrown into the unstable region.

Formally, we follow the empirical approach of Aruoba, Cuba-Borda, and Schorfheide (2018) and compute the multiplier

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

respectively, for economies where the binding ZLB is caused by initial severe pessimism ($* = P$) and expectational shocks ($* = S$). In Equation (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 deflationary spiral 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 Equation (5). Notice that the numerator of Equation (13) involves the values of output realized in period $t + 1$, that is, immediately after the fiscal shock g_t. This is because realizations of output in period t are not affected by public expenditures in period t (see Equation (1)), because they only depend on expectations formed at the beginning of period t, that is, before the implementation of fiscal policy.

The values of the multipliers for treatments FP and FS are reported, respectively, in Figures 8 and 9. The cumulative multiplier over Periods 1–4 for treatment FP is about 1.77 while, for treatment FS, the cumulative multiplier over Periods 8–10 is roughly 1.1.[27] Overall, the estimated values above 1 suggest that expansionary fiscal policy crowds in private consumption.

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, that is, when the economies are already converging toward the targeted equilibrium and expectations are in the "stable" region. Therefore, following the first bad news announcement, output and inflation do not drop dramatically because expectations are still in the "stable" region. Only after the last bad news announcement do expectations fall into the "unstable" region, triggering a self-reinforcing deflation and a large drop in output. These periods of deep recession leading to higher values of the numerator in Equation (13) do not have an impact in the computation of the multiplier, as typically the fiscal rule succeeds in creating

27. 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 23). 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 cumulative multiplier of about 1.65.

FIGURE 8
Treatment FP

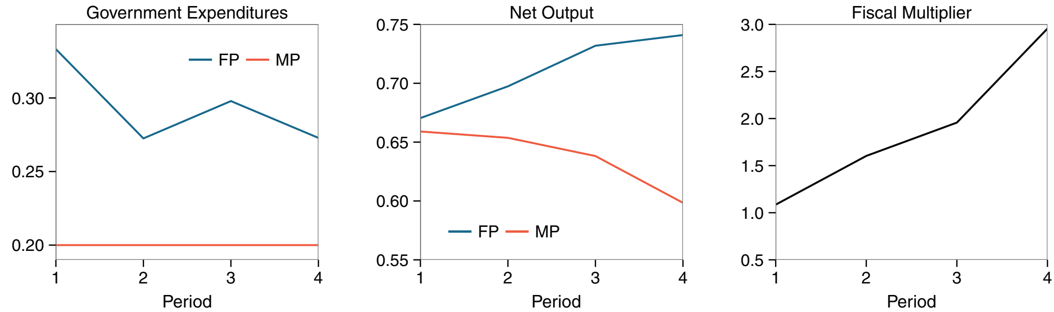
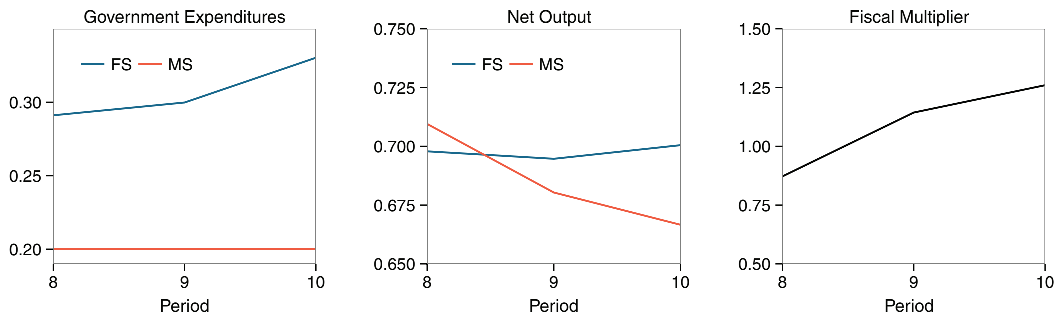


FIGURE 9
Treatment FS



inflationary expectations immediately after the last expectational shock.

By contrast, in treatment MP, expectations are severely pessimistic, that is, lie within the "unstable" region, right from the beginning of the experiment. Particularly, low inflation expectations imply particularly high expected real interest rates (i.e., R_t/π^e_{t+1} in Equation (1)), which cause large drops in consumption, and lead to higher values of the numerator in Equation (13). Therefore, the more pessimistic expectations, the stronger the deflationary and depressive dynamics, and the higher the magnitude of the fiscal multiplier in treatments with the policy mix.

B. Discussion with the Literature on Fiscal Multipliers

The literature provides only few, and no consensual, estimates of the fiscal multipliers during a recession.

This is mainly due to the lack of data, as episodes of deep recessions are rare, and the use of linear frameworks in which the modeling of state dependence is difficult (see Parker 2011 for a discussion). An example is Auerbach and Gorodnichenko (2012), who use a structural VAR model with regime switching, and find that fiscal multipliers are much higher in recessions, ranging between 1 and 1.5, than in expansions (see also Tagkalakis 2008 and Braun, Korber, and Waki 2012). In the DSGE literature, fiscal multipliers may be typically larger than one during economic downturns once the ZLB is binding (Christiano, Eichenbaum, and Rebelo 2011), or if the liquidity trap is expected to be long-lasting (Erceg and Lindé 2014). Christiano, Eichenbaum, and Rebelo (2011) find values as high as 3.7 in their baseline model. Furthermore, Mertens and Ravn (2014) find larger multiplier values under adaptive learning than under RE.[28]

28. However, their estimates are lower than one in both cases.

The orders of magnitude that we compute from our experiment appear very reasonable in light of those findings.

Importantly, the controlled lab environment enables us to isolate the channel through which fiscal policy influences output—in our case, the expectation channel, which is a non-negligible advantage given how hard it is to disentangle the different channels in field data. The expectational channel of fiscal policy is crucial in our experimental setting as net output c is not directly influenced by g, but depends on expected net output c^e_{t+1} and the expected real interest rate R_t/π^e_{t+1} (see Equation (1)). The possibility for fiscal policy to crowd in or out private consumption then directly operates through the *expectation feedback mechanism*: an increase in g directly impacts inflation (by assumption of the policy rule (4)), and our experiment shows how the fiscal shock then feeds back into inflation expectations, which increases output (through the decrease in the real interest rate at the ZLB in the Euler relation (1)) and output expectations.

In that sense, our fiscal multipliers are closest to the effects of fiscal policy obtained while simulating NK models at the ZLB as in, for example, Eggertsson (2010) and Christiano, Eichenbaum, and Rebelo (2011), where fiscal expansion can counteract a deflationary spiral by creating inflationary pressures and a stimulating drop in the real interest rate. A major difference though is that in those models, an exogenous shock causes the ZLB to bind, and fiscal policy aims to mitigate the output losses throughout the liquidity trap episode, that lasts for a given, *policy-invariant* period of time. However, the model properties and the policy implications can be quite sensitive to this design (Aruoba, Cuba-Borda, and Schorfheide 2018). By contrast, one of the major contributions of our experiment is to analyze how policies affect expectations when the occurrence of liquidity traps is entirely expectation driven, the policy mix influences the economy through the expectation feedback mechanism, which in turn endogenously determines the transitory dynamics along the recovery, but no specific assumption has to be made on the expectation formation process.

To conclude, our computation method of the fiscal multipliers accounts for the different dynamics of expectations that arise in different treatments due to different policy experiences and interestingly complements empirical or theoretical approaches that are confronted to a number of difficulties in isolating and quantifying the expectation channel of fiscal policy.

VI. CONCLUSIONS

The aftermath of the 2007–2008 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 article, we use a controlled laboratory environment where expectations are directly elicited from paid human subjects as a "testbed" for policies against deflationary outcomes. In particular, we use an LtFE to measure the effects of monetary and fiscal policies on expectations when deflationary pressures are expectation driven in a standard, widely used NK macroenvironment.

Our results are in line with those obtained in the adaptive learning macroeconomic 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 beyond a worrisome threshold. On the contrary, fiscal stimulus at the ZLB is successful in avoiding unstable deflationary and depressive dynamics and guaranteeing convergence to the targeted equilibrium.

We further shed light on 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 pessimistic expectations persistent, and low inflation levels together with near-zero interest rates long-lasting.

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. We find values of the fiscal multiplier larger than one, values that are consistent with the few available empirical estimates in recession times. We emphasize 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 the dynamics of inflation and output involve only one-step ahead expectations, and longer horizons are ignored. Due to its simplicity, this is a valid and convenient approach to implement in the lab. One drawback of this approach is that it does not allow for the possibility of considering beliefs on how deficit will be financed. Preston (2005) introduces an alternative approach, namely, "infinite-horizon learning," in which agents use forecast of the whole time path of future variables to make current economic decisions.[29] Considering longer horizon expectations is especially interesting in the context of fiscal policy, as it allows to consider additional relevant channels, namely, the effects of temporary increases in public expenditures on future expected taxes, which may mitigate the demand stimulus that we have highlighted in this article. Benhabib, Evans, and Honkapohja (2014) have extended the analysis of the policy mix considered in our experiment under adaptive learning in an infinite-horizon framework, and 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.

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29. See Honkapohja, Mitra, and Evans (2013) for a comparison between Euler and infinite horizon learning.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

Appendix S1. Supporting Information