Escaping secular stagnation with unconventional monetary policy*

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November 2021

Abstract

We design a new experimental framework to study policy interventions in secular stagnations and liquidity traps using an overlapping-generations environment where participants form expectations and make real economic decisions. We explore the ability of unconventional monetary policy to lead economies out of deflationary traps and away from a binding zero lower bound. We observe that participants are able to coordinate on high inflation full-employment equilibria. Permanent exogenous deleveraging shocks induce pessimistic expectations and persistently deflationary episodes. These shocks generate considerable consumption and expectations heterogeneity and also change subjects' forecasting heuristics to make them more backward-looking. Permanently increasing the central bank's inflation target is insufficient to generate inflationary expectations. However, eliminating the zero lower bound is consistently effective at stimulating spending and generating the necessary inflation for the economies to escape the zero lower bound. Negative interest rates are more potent than raising the inflation target at shifting consumption to the present. Our findings suggest that inflation expectations and demand is better stimulated through realized wealth effects than coordination on rational expectations equilibria.

JEL classifications: C9, D84, E52, E58

Keywords: expectations, monetary policy, secular stagnation, liquidity trap, communication, credibility, laboratory experiment, experimental macroeconomics

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*We thank the Social Science and Humanities Research Council of Canada and the National Science Foundation for generous financial support. We have benefited from useful comments and suggestions from Robert Amano, Alex Brown, Gabriele Camera, Thomas Carter, David Freeman, John Duffy, Catherine Eckel, Janet Hua Jiang, Pedro Bento, Daniela Puzzello, Isabelle Salle, Tatevik Sekhposyan, Sarah Zubairy, John Duffy, and seminar audiences at Chapman University, Texas A&M University and University of Arkansas, and conference audiences at the 2019 SEF Asia Pacific Regional Conference and 2019 North American ESA Meetings. All remaining errors are our own. † Petersen: Department of Economics, Simon Fraser University, 8888 University Drive, Burnaby, BC, V5A 1S6, Canada, lubap@sfu.ca. Rholes: Department of Economics, University of Oxford, 10 Manor Road, Oxford, Oxfordshire, England, ryan.rholes@economics.ox.ac.uk

1 Introduction

Many developed economies exhibit tell-tale symptoms of secular stagnation: decades-long downward trends in natural interest rates, tepid output growth well below estimates of potential, growing debt-to-GDP ratios, negative real interest rates, and below-target inflation. these conditions persisted despite expansionary policies employed by the Federal Reserve and by other central banks. For instance, the United States spent seven years at its zero lower bound (ZLB) before lifting off in 2015 and slowly climbed up to a meager 2.25% by 2019 thanks to, among other things, extraordinary quantitative easing and forward guidance. Summers (2019) argued that this was insufficient space to operate in a future recession. At the 2019 Jackson Hole Economic Policy Symposium, Federal Reserve Chairman Jerome Powell described this proximity to the effective lower bound as "the pre-eminent monetary policy challenge of our time" as central bankers sought fresh policy tools.

Monetary interventions once considered too extreme or perhaps outlandish are now finding their way into mainstream policy discussions. Many central bankers are now giving serious consideration to raising inflation targets and implementing negative policy rates, both of which would, in theory, stimulate inflation expectations and propel economic activity. However, policymakers are hesitant to adopt these tools given the limited evidence on their efficacy.

In this paper, we build a flexible and novel experimental environment to test-bed these unconventional policies, thereby providing policy makers with much-needed, timely evidence on their effectiveness. Importantly, this environment, though tractable, captures many realistic and pressing concerns by allowing for secular stagnation and liquidity traps at the zero lower bound. We use this framework to provide the first experimental evidence on the potency of raising the inflation target and negative nominal interest rates in combating secular stagnation.

To this end, we adapt Eggertsson, Mehrotra, and Robbins (2019, EMR henceforth) to the lab. In each experimental economy, groups of participants form inflation expectations and make financial decisions together with automated firms and policy makers. We expose each economy to an exogenous deleveraging shock that should generate pessimistic inflation expectations, depress consumption spending, and a secular stagnation of the economy.

In our *Baseline* treatment, we find that most economies converge to a unique full-employment equilibrium. The exogenous deleveraging shocks consistently generate pessimistic expectations and typically manufacture various degrees of instability manifesting permanent deflation. In most sessions the economies converge in the direction of the secular stagnation equilibrium. We then explore alternative policy options to return economies to the full-employment equilibrium after an extended episode at the zero lower bound.

In our *HigherTarget* treatment, we allow a mechanistic central bank to permanently increase its inflation target, which is a policy prescription formalized by EMR. Doing this introduces a multiplicity of locally determinate equilibria, leading to an equilibrium selection problem. This intervention does not effectively return any of our experimental economies to the targeted, full-employment equilibrium. This intervention fails because it cannot re-coordinate the expectations of dynamically-optimizing agents.

In our *NegativeIR* treatment, we instead allow the central bank to use negative interest rates (i.e. we remove the ZLB constraint on policy). Negative policy rates consistently stimulate consumption, which in turn encourages inflationary expectations and a quick escape from the ZLB. These economies converge quickly to the unique full-employment equilibrium that coincides with the central bank's inflation target.

We see in all treatments that deleveraging shocks generate considerable consumption heterogeneity. Thus, the decrease in welfare is larger for some subjects than others following these shocks. We also observe that deleveraging shocks effect expectations formation. Instability brings about a high level of constant gain learning and other backward-looking heuristics.

The main takeaway from our experiments is that negative interest rates are more effective than raising inflation targets at shifting consumption to the present and stimulating an economy out of secular stagnation. Our findings suggest that inflation expectations and demand are both better stimulated through realized wealth effects than coordination on rational expectations equilibria. Our participants fail to perceive a central bank's higher inflation target credible after an extended period of deflation.

We also make a number of valuable methodological and empirical contributions in this paper. First, we demonstrate how a complex general equilibrium theoretical framework can be distilled to a simple implementation that nonetheless allow for a meaningful interaction of expectations, decisions, and monetary policy. This framework can flexibly be extended to allow for fiscal policy, credit markets, policy communication and coordination. Additionally, we contribute to the experimental literature by bridging learning-to-forecast and production economy experiments. Fusing these frameworks allows us to link expectations and real decision in response to policy, filling a crucial but neglected empirical gap.

The rest of the paper is organized as follows. Section 2 places our paper in the context of the existing macroeconomics and experimental research. Section 3 lays out the theoretical framework and hypotheses for our experiment. Section 4 provides details of the experimental implementation, Section 5 presents our experimental results, and Section 6 concludes.

2 Literature

This paper makes important contributions to the macroeconomic literature on economic growth and policy, as well as the experimental macroeconomic literature. We discuss these contributions below.

2.1 Theoretical and Empirical

The existing liquidity trap literature, though large, does not provide a thorough treatment of secular stagnation. As highlighted by EMR, this is because most models employ representative agent frameworks[1] where the long-run interest rate is uniquely determined by a representative discount factor. Since the real interest rate must eventually revert to a positive long-run level, ZLB episodes triggered by transitory shocks are themselves temporary. This theoretical outcome yields a 'wait-and-see' policy approach to liquidity traps, which would constitute an obvious failure of policy for an economy facing secular stagnation. To circumvent this issue and allow for permanently-negative neutral real interest rates, EMR introduce ZLB episodes into an OLG model (This was first shown by Samuelson (1958)).

Deflationary steady-states can emerge in the New Keynesian framework. Benhabib, Schmitt-Grohe and Uribe (2001), Schmitt-Grohe and Uribe (2017), and Benigno and Fornaro (2015) all feature a ZLB that binds due to hysteresis. However, ZLB steady-states in these models are locally indeterminate and are open to the criticism that ZLB episodes driven by hysteresis are not 'learnable' and it is therefore unclear how such a steady-state can coordinate expectations (Christiano, Eichenbaum and Johannsen, 2016). However, Arifovic, Schmitt-Grohe, and Uribe (2018) show that the liquidity trap equilibrium is learnable under social learning. Additionally, Gibbs (2018) shows mathematically that both the deflationary and targeted-inflation equilibrium in EMR's model are both E-stable when they exist and that the full-employment, liquidity trap equilibrium is only stable whenever agents in this OLG model face sufficiently large borrowing limits.

[1]See Krugman (1998), Eggertsson and Woodford (2003), Christiano, Eichenbaum and Rebelo (2011), Eggertson and Krugman (2012), and Werning (2012) for examples.

There is very limited evidence on the ability of central banks to increase inflation expectations by *raising* their inflation target. Most inflation targeting central banks have kept their inflation targets constant or reduced them after stabilizing their price level growth. There are two exceptions. The Reserve Bank of New Zealand (RBNZ) first began targeting inflation in the range of 0 to 2 percent, and were quite effective in bringing inflation down from well over 6 percent in 1990 to an average of 2.8 percent in the five years that followed. In 1996, the RBNZ increased the upper bound of their range to 3 percent, effectively raising the midpoint from 1 to 1.5 percent. From 1996 to 2002, inflation averaged 1.8 percent, converging right toward the mid-point of the target range. In 2003, the Bank raised the lower bound of the range from 0 to 1 percent, increasing the midpoint to 2 percent. Over the next five years, average inflation rose to 2.8 percent, and from 2003-2019, averaged 2 percent. More recently, the Bank of Japan (BoJ) experimented with communicating an explicit inflation target and raising its target. In February 2012, the BoJ announced that it would explicitly target inflation at 1 percent (this had been the implicit mid-point of an acceptable range of inflation since 2006). This announcement led to a modest reduction in deflation. In January 2013, BoJ further increased its target from 1 to 2 percent. While there was some rapid inflation growth over the following year, inflation has fluctuated between 0.5-1%. Overall, it appears that raising the target had a positive effect on inflation, albeit smaller than intended.

Finally, this paper contributes to an emerging literature that studies the use of negative policy rates. This literature, while very important, is woefully incomplete due to a lack of observational data. Eggertsson, Juelsrud, Summers, and Wold (2019) use empirical data to show that negative policy rates produce a lower bound on household deposits (DLB). They embed this DLB into a banking sector model and show that negative rates are expansionary only under some conditions. Altavilla, Burlon, Giannetti, and Holton (2019) use Euro-area data to show empirically that the transmission mechanism of monetary policy does not break down when rates become negative. Wu and Xia (2016) build a shadow rate term structure model (SRTSM) calibrated to the Euro Area and show that all four of the ECB's negative rate cuts lowered maturities along the short-end of the yield curve. Further, they show that forward guidance may facilitate the transmission of negative rates.

Crucially, no real-world implementation of negative rates has led to banks applying negative rates to household deposits, perhaps out of fear that negative commercial deposit rates will cause households to hoard cash. This experimental framework fills two critical gaps in the data by producing studying how negative rates with complete pass thru impact intertemporal choices and by provide original evidence on portfolio choice in response to negative interest rates.

2.2 Experimental Macroeconomics

Begun largely in response to an invitation from Robert Lucas (1986), experimental macroeconomics is a relatively young but fruitful field of study focused on testing the microfoundations of modern macroeconomic models in a controlled, laboratory setting (see John Duffy (2016) for a thorough survey of the literature). Several branches of literature from this emergent field relate closely to our research.

Dynamic Optimization & Learning to Optimize in Individual and Production Economies Settings Laboratory experiments testing the ability of people to solve dynamic optimization problems in the form of a one-sector, infinite-horizon model reveal that experimental subjects (relative to theoretical predictions) do a poor job of consumption smoothing (consumption often too closely tracks current income) and that agents' consumption decisions are not time-independent (For examples, see Hey and Dardanoni (1988), Carbone and Hey (2004), Noussair and Matheny (2000), Lei and Noussair (2002), Ballinger et al. (2003), Carbone (2006), Crockett and Duffy (2013), Carbone and Duffy (2014) and Meissner (2016)). Possible explanations for such failures are binding liquidity constraints, precautionary saving, and debt aversion. There are some exceptions, however. Crockett and Duffy (2013) finds that subjects facing a concave utility function are able to optimize within the framework of a Lucas Tree model (Duffy (2016), Lucas (1978)). Miller and Rholes (2020) find that allowing for joint decisions, rather than individual decisions, improves choices in the optimization task (relative to the representative benchmark) by about 40%.

The model we test here relies crucially on households making optimal consumption and borrowing decisions over a life cycle. Inefficient behavior in one portion of the life cycle - under- or over-borrowing while young, for example - has meaningful implications for the aggregate economy in later parts of the life cycle. The model we test assumes agents have perfect foresight and that agents always borrow and spend along optimal paths. Thus, a potential pitfall here is the inability of real people to correctly solve the life-cycle problem. This failure would drastically decrease aggregate stability and undermine equilibration. Importantly, it could potentially mute the effects of policy interventions that operate on the economy my moderating intertemporal choice (i.e. shifting demand by manipulating rates or influencing inflation expectations).

Production economy experiments involve studying the simultaneous coordination of decisions of multiple agents in settings with input and output markets. Such experiments have been used to study patterns of international trade, exchange rates, economic growth and rationing (Lei and Noussair, 2002; Noussair et al. 1995, 1997, 2007; Fenig and Petersen, 2017). Our experiment will introduce an overlapping generations (OLG) structure to this production framework. Overlapping generations models have been taken to the lab to study inflation (Arifovic, 1995), fiscal policy (Van der Heijden et al., 1998), and coordination (Offerman et al. 2001). We make two methodological contributions to this literature. First, we introducing a novel approach to implementing OLG economies in the laboratory by having participant interact in only one phase of their life-cycle. Second, we introduce a pricing algorithm based on numerical methods that facilitates laboratory experimentation with models whenever closed-form price equations are not feasible.

Expectations and Learning to Forecast In addition to the importance of optimal consumption/borrowing behavior in models of secular stagnation, there exists much experimental work to guide our implementation and understanding of expectations elicitation. Our experimental framework assume agents are able to both forecast and optimize simultaneously. In particular, subjects are able, while young, to perfectly forecast future (middle-aged) income and then borrow optimally against this forecast. This use of rational expectations to close self-referential models allows market clearing where otherwise yet unrealized information would serve as an obvious impediment. As noted by Duffy (2016), this assumption disallows testing of theoretical models using real-world empirical data since any failure of the data to match theoretical predictions could be driven either by faulty expectational assumptions or by some other aspect of the model. Much of the existing experimental literature fails to provide support for the rational expectations assumption (discussed by Camerer (1998), Ochs (1995), Duffy (2016)). Nevertheless, rational expectations dominates macroeconomic literature and so eliciting expectations is a fundamental component of testing macroeconomic theory in the laboratory.

The primary approach used within the literature is the 'learning-to-forecast' model initiated by Marimon and Sunder (1993, 1994, 1995) and developed by Heemeijer et al. (2009) and Hommes (2011), whereby subjects' elicited price forecasts simultaneously determine automated demand decisions of traders and aggregate price outcomes. This method complements the 'learning-to-optimize' approach used in the literature described earlier in this section. The combination of price expectations and decisions have been studied in Bao et al. (2012), Petersen and Winn (2014), and Petersen (2016). We incorporate both approaches into our experiment. Subjects in our experiment provide price expectations that then determine projected borrowing constraints and budgets. Subjects use these budgets to make borrowing and savings decisions.

Monetary Policy Experiments This paper also contributes to an emerging literature on liquidity traps. Arifovic and Petersen (2017) show in a learning-to-forecast experiment that expectations significantly overreact to exogenous demand shocks and that neither qualitative nor quantitative communication of a central bank's higher inflation target can effectively rescue an economy mired in a deflationary trap. However, the authors do find that quickly applied and certain fiscal stimulus can stabilize expectations and facilitate economic recovery. Hommes, Massaro, and Salle (2015) also find that fiscal stimulus is effective at mitigating deflationary spirals. Ahrens, Lustenhouwer, and Tettamanzi (2017) extend Arifovic and Petersen by allowing for human vs. robotic central bankers. They find that human central bankers can more effectively build up credibility by slowly adjusting their inflation projections upward while at the ZLB. Our paper is the first to explicitly study the effects of raising the inflation target on both expectations and real decisions.

More generally, learning-to-forecast experiments have been used to study a host of questions related to central bank communication: the construction and communication of interest rate projections and macroeconomic projections (Kryvtsov and Petersen, 2015, 2020; Mokhtarzadeh and Petersen, 2017; Ahrens et al., 2017), the communication of inflation targets (Cornand and M'Baye, 2016), and macroeconomic literacy training (Mirdamadi and Petersen, 2018). In general, these experiments highlight the importance of simple, easy-to-understand communications and information in guiding expectations to the rational expectations equilibrium.

Macroeconomists have also studied monetary policy-relevant questions in production economy settings. Bosch-Domènech and Silvestre (1998) and Lian and Plott (1997) Fenig et al. (2018) study monetary policy in a production economy where households may also trade in speculative asset markets. They show that a 'leaning-against-the wind' monetary policy that raises the nominal interest rates with asset price inflation can be effective in stabilizing asset prices with little consequence for the real side of the economy. In their environment, nominal interest rates are unbounded and can become significantly negative. This serves to fuel asset price bubbles.

Our paper builds on this research by providing the first study to compare the effects of bounded and negative interest rates on consumption-saving decisions. We find that negative interest rates propel consumers to shift consumption to the present.

3 Theoretical Framework and Hypotheses

3.1 Households

Consider an economy with young, middle-aged, and old households. Households derive utility from a single consumption good, C_t. Young households receive no income. Instead, they borrow from middle-aged households but face an exogenous borrowing constraint D_t[2], which constitutes some proportion of middle-aged income. Middle-aged households earn income from the inelastic provision of labor, $\overline{L}$, and from firm profits Z_t. These households repay debt accrued while young, and then split remaining money between consumption and savings. Old households consume with savings. A one-period, risk-free bond facilitates lending and borrowing (between middle-aged and young households) in the loanable funds market.[3] Additionally, households trade one-period debt denominated in money. The central bank controls the per-period nominal rate of return, i_t, on this asset. Thus, households maximize:

$$E_t\{ln(C_t^y) + \beta ln(C_{t+1}^m) + \beta^2(C_{t+2}^o)\} \tag{1}$$

subject to the following budget constraints:

$$(1 + g_t)B_t^y = -B_t^m \tag{2}$$

$$C_t^y = B_t^y = \frac{D_t}{1 + r_t} \tag{3}$$

$$C_{t+1}^m = \frac{W_{t+1}}{P_{t+1}}L_{t+1} + \frac{Z_{t+1}}{P_{t+1}} - (1 + r_t)B_t^y + B_{t+1}^m \tag{4}$$

$$C_{t+2}^o = (1 + r_{t+1})B_{t+1}^m \tag{5}$$

$$i_t \geq 0 \forall t \tag{6}$$

[2]This is taken within the theory to be some exogenous debt constraint that the authors use to introduce debt deleveraging shocks.

[3]This implies that equilibrium in the bond market requires that the borrowing of the young match the savings of the middle-aged.

Note that W_t, P_t, B^y_t, B^m_t represent nominal wages, the aggregate price level, borrowing of the young, and savings for the middle-aged in some period t. Equation (3) implies that D_t is always binding, Equation (5) implies that old households consume all income, and Equation (6) implies a binding ZLB. This maximization problem yields the Euler equation

$$\frac{1}{C^m_t} = \beta \mathbb{E}_t \frac{1}{C^o_{t+1}}(1+i_t)\frac{P_t}{P_{t+1}} \tag{7}$$

3.2 Firms

Firms are perfectly competitive price takers with technology $Y_t = L^\alpha_t$ that maximize profits via an optimal hiring decision:

$$\frac{W_t}{P_t} = \alpha L_t^{\alpha 1} \tag{8}$$

Without no source of market friction, dynamics would match those of an endowment economy and Equation (8) would pin down real wages. Thus, the model includes wage rigidity. Workers do not work for wages that fall below some threshold comprising a convex combination of a the flexible wage, $W^{flex} = \alpha P_t L_t^{\alpha-1}$, and wages from the previous period, W_{t-1}. Thus, wages in this model are given by

$$W_t = max\{W_t, W_{t-1} + (1-\gamma)W^{flex}\} \tag{9}$$

where $\gamma \in [0, 1]$ represents the degree of nominal wage rigidity in the economy. Note that $\gamma = 0, \gamma = 1$ describe fully flexible wages and complete wage rigidity, respectively. Whenever W_t equals the fully flexible wage, then an economy is experiencing inflation and labor markets clear without rationing. Otherwise, an economy experiences deflation and firms ration labor uniformly.

3.3 Central Bank

A mechanistic central bank sets nominal rates according to a Taylor-type monetary policy rule

$$1 + i_t = max\left(1, (1 + i^*)\left(\frac{\Pi_t}{\Pi^*}\right)^{\phi_\pi}\right) \tag{10}$$

where i^* is the steady-state nominal interest rate, Π^* is the central bank's gross inflation target, and $\phi_\pi > 1$ is the central bank's reaction coefficient to deviations of inflation from the inflation target. Gross inflation is given by $\Pi_t = \frac{P_{t+1}}{P_t}$. The assumption of perfect foresight, combined Equation (7), implies a standard Fisher equation:

$$(1 + i_t) = (1 + r_t)\frac{P_t}{P_{t+1}} \tag{11}$$

This, coupled with the binding ZLB, places a lower bound on the inflation rate for a constant-inflation equilibrium:

$$\Pi(1 + r) = 1 + i \geq 1 \implies \overline{\Pi} \geq \frac{1}{1 + r} \tag{12}$$

EMR note that this bound is meaningful whenever there is a permanently negative real rate because it implies that steady-state inflation must remain positive.[4]

3.4 Equilibrium

Whenever economies face deflation, the long-term nominal rigidities prevent the emergence of market clearing wages. Thus, the real cost of wages rises causing firms to ration labor demand and an output gap to emerge. Whenever $\Pi \geq 1$, then $L_t = \overline{L}^\alpha, W_t = W^{flex}$, and there is no output gap so that $Y_t = \overline{L}^\alpha = Y^f$.

[4] For example, a natural rate of -4% implies a lower bound on inflation of 4%, which precludes the existence of an inflation target below 4% whenever prices are flexible. Otherwise, there would not exist an equilibrium. Hence the introduction of nominal wage rigidities as a source of market friction.

AS is then split into:

$$Y_t = \overline{L}^{\alpha}, \qquad \Pi \geq 1 \tag{13}$$

$$Y_t = Y_f \left(\frac{\gamma - \Pi}{\Pi(\gamma - 1)} \right)^{\frac{\alpha}{1-\alpha}}, \qquad \Pi < 1 \tag{14}$$

where Equation (13) describes the vertical portion of the AS curve and Equation (14) the upward sloping portion of the AS curve.[5] Note that the degree of wage rigidity γ dictates the slope of the upward sloping portion of the AS curve and can, under certain conditions, determine both the existence and uniqueness of a deflationary equilibrium.

AD is split into:

$$Y = D + \frac{(1+\beta)(1+g)D}{\beta} \frac{1}{\Pi^{\phi_\pi - 1}} \frac{(\Pi^*)^{\phi_\pi}}{(1+i*)}, \qquad i > 0 \tag{15}$$

$$Y = D + \frac{(1+\beta)(1+g)D}{\beta} \Pi, \qquad i = 0 \tag{16}$$

3.5 Monetary Policy

Using the equilibrium equations described above, we assume the following parameter values for discussion in this section:

$\Pi^* = 1.1, \phi_\pi = 2, \gamma = .3, Y_f = 1, \alpha = .7, \beta = 1, g = 0, L = 1$, which are the inflation target, a measure of the central bank's responsiveness to the inflation gap, the degree of wage rigidity, the level of full-employment output, output elasticity of labor, the discount factor, population growth rate, and the inelastic labor supply, respectively. Households face two decisions during the full lifecycle: a borrowing decision while young and a consumption/savings decision while middle-aged. These two decisions drive the dynamics of this model. The concavity of the utility function is such that an optimizing middle-aged agent must consumption smooth. Savings from this cohort flows into the loanable funds market. Demand for loanable funds originates exclusively from the constrained borrowing decisions of the young.

[5] The theory assumes that expectations adjust so that there is no trade off between unemployment and inflation in environments characterized by permanently high inflation. However, this same assumption does not carry over to environments characterized by low inflation or deflation. Hence, the upward sloping portion of this supply curve.

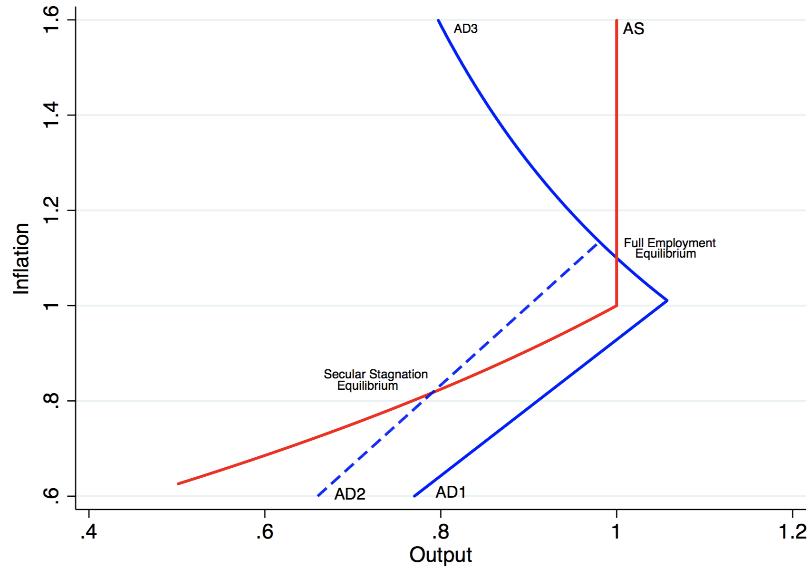


Figure 1: A deleveraging shock moves an economy from a unique inflationary to a unique secular stagnation equilibrium.

To understand the impact of a deleveraging shock, suppose an inflationary economy faces a reduction in the amount of money that Young households may borrow for consumption. This causes a sharp decrease in the demand for loans but not the supply of loanable funds which, in turn, causes the market clearing interest rate to fall. Thus, the young who face a deleveraging shock in period t will have excess resources in period $t+1$. This causes an increase in the supply of loanable funds in $t+1$, further decreasing the interest rate. This translates into a decrease in AD as consumption becomes increasing desirable relative to saving. We illustrate the impact of such a shock on inflation-output dynamics in Figure 1.

The downward sloping portion of AD is described by Equation (15) and the upward sloping portion by Equation (16).[6] Importantly, shocks to D can eliminate a unique inflationary equilibrium and create instead a deflationary equilibrium. We set the pre-shock value of $D = 35\%$, which yields a unique inflationary equilibrium with 10% inflation. This equilibrium occurs where AD3 intersects AS in Figure 1. A deleveraging shock reduces the borrowing constraint to $D = 30\%$, which shifts the upward sloping demand curve in Figure 1 inward and yields a unique secular stagnation equilibrium where AD2 intersects AS. The predictions of the model yields the following two hypotheses:

[6] A shock to D impacts both segments of the curve but that this shock is offset by a simultaneous adjustment of i* in Equation (15) so that only the upward sloping portion of the AD curve shifts significantly upon impact of a deleveraging shock.

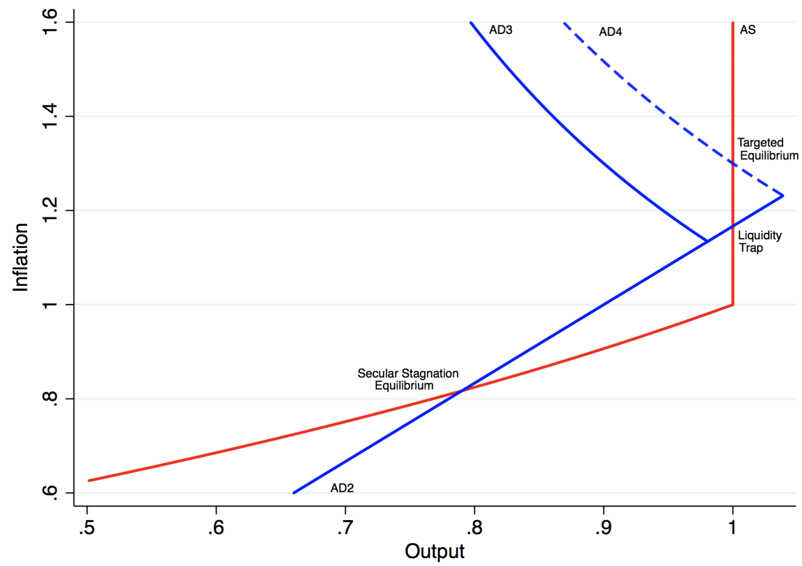


Figure 2: Increasing the inflation target generates two inflationary equilibria: a target, full-employment equilibrium and a liquidity trap equilibrium.

H1. The economy stabilizes at the unique inflationary equilibrium in the pre-shock phase.

H2. A sufficiently large deleveraging shock will cause an economy to stabilize at the secular stagnation equilibrium.

The mechanistic central bank is bound by the ZLB and so instead addresses secular stagnation via inflation targeting. Suppose that the central bank raises its inflation target from its baseline level of to $\Pi^* = 10\%$ to $\Pi^* = 30\%$. This shifts the downward sloping sloping portion of the AD curve rightward in Figure 2 from AD3 to AD4, guaranteeing the existence of two inflationary equilibria: a full-employment, targeted equilibrium (where AD4 intersects the vertical portion AS) and the liquidity trap equilibrium (where AD2 intersects the vertical portion of AS). However, equilibration following this policy action hinges on the assumption that households are rational, which is a particularly vulnerable assumption.

The increase in inflation target from 10 to 30% is certainly extreme but serves several purposes. First, it allows sufficient separation between the liquidity trap and targeted equilibria so that we can cleanly observe equilibrium selection with potentially boundedly rational participants. Second, we want to avoid the homegrown biases participants may exhibit with more familiar inflation targets. A baseline inflation target of 10% would be sufficiently out of the recent inflation experiences of most of our North American student populations.

Increasing the inflation target three-fold during the secular stagnation brings needed attention to the Bank's objectives since garnering the public's attention is a necessary component for the success of a policy intervention meant to operate primarily thru the expectations channel (Sims 2003; Gabaix 2020).

The limited empirical evidence that we do have on stimulating inflation expectations via increasing an inflation target highlights the need for extreme policy action. Even when Japan doubled its inflation target from 1 to 2 percent in January 2013, this was insufficient to generate sufficiently inflationary expectations. It is reasonable to think that a central bank employing this unconventional policy in the real-world would want to more-than-double its inflation target to circumvent a timidity trap (Krugman, YEAR). This intuition is nicely captured by former Federal Reserve governor Randall Kroszner who said at the 2019 Jackson Hole Symposium that central bankers were searching for a "shock and awe strategy...to make sure that markets realise they're serious, and that they are going to have an impact".

H3. Raising the inflation target to a sufficiently high level will move an economy out of secular stagnation stagnation to the targeted inflationary equilibrium.

We also consider the possibility that our mechanistic central bank can allow nominal interest rates to decrease below zero. The idea of using negative rates has gained in popularity over that last two decades as many advanced- and emerging-economy central banks find themselves constrained by the ZLB. There is some evidence that banks may be able to succesfully employ negative rates. Eggertson, Juelsrud, Summers, and Wold (2019) show that, under some conditions, negative nominal rates are expansionary. Altavilla, Burlon, Giannetti, and Holton (2019) use Euro-area data to show empirically that the transmission mechanism of monetary policy does not break down when rates become negative.

Clearly, allowing our mechanistic central bank to set negative nominal rates violates Equation (6). Removing this constraint removes the kink in the AD curve, so that AD is fully describe by Equation (15). We show in Figure 3 that this change eliminates the unique secular stagnation equilibrium and recreates the full-employment equilibrium that coincides with the central bank's 10% inflation target. This yields the following hypothesis:

H4. Eliminating the ZLB moves an economy out of secular stagnation and back to the targeted inflationary equilibrium.

It is unclear ex ante whether or not this should be effective. It is quite possible that such an intervention will prove ineffective if subjects fail to fully appreciate the implications of negative interest rates. Subjects' consumption decisions may instead overreact to such an intervention, driving an economy out of a deflationary trap to some point beyond the

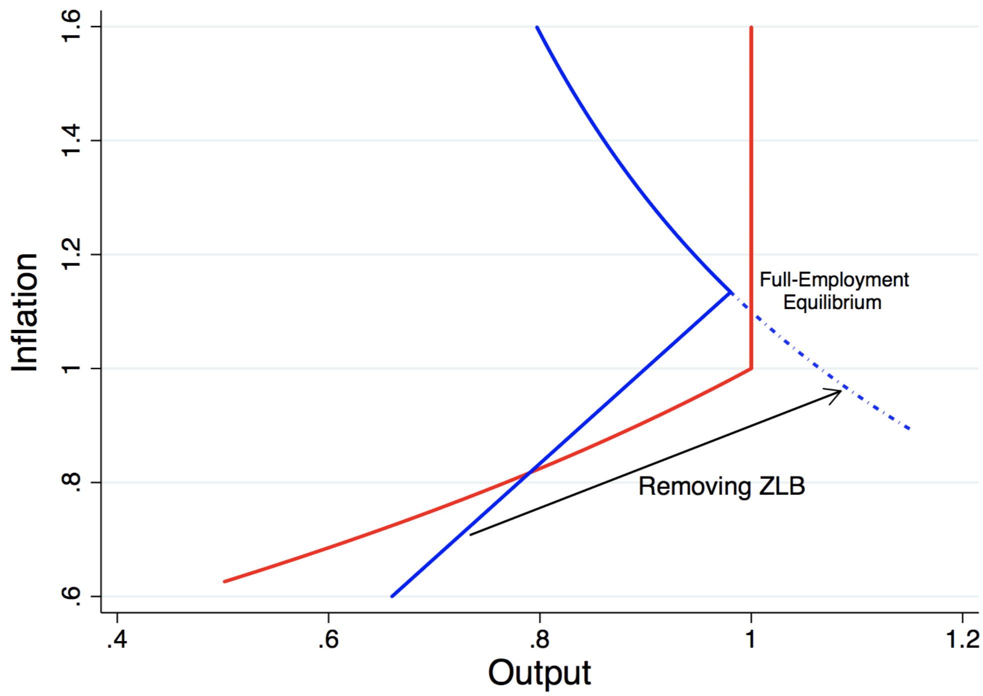


Figure 3: Removing the ZLB removes the kink from the AD curve, thereby eliminating the secular stagnation equilibrium and creating instead a unique inflationary equilibrium.

intended inflationary equilibrium.

H5. Introducing a portfolio choice between bonds and cash mutes the efficacy of eliminating the ZLB.

Finally, we study how subjects' portfolio decisions respond to negative rates. The vast majority of commercial banks subjected to negative interest rates by their respective central banks refused to pass these negative rates thru to commercial deposit rates out of fear that households would choose to hold cash in response. This hypothesis follows that real-world logic by supposing that introducing a portfolio choice into our negative rates treatment will lead subjects to hold cash rather than bonds whenever rates become negative. This decreases aggregate demand in equilibrium, thereby muting the effectiveness of negative interest rates. Intuitively, this is akin to allowing our experimental subjects to opt back into a world where the zero lower bound is binding. This effectively reintroduces the kinked aggregate demand curve, restoring the secular stagnation equilibrium.

4 Experimental Implementation

We develop a new experimental environment to study expectations and economic decisions at the zero lower bound. While previous experimental work on the zero lower bound focuses solely on expectation formation, our framework will make two important contributions. First, we introduce an unexplored secular stagnation equilibrium, expanding the set of possible research questions. Second, our environment allows for the simultaneous study of expectations and financial decisions, which yields a richer and more realistic environment within which researches can explore of how policy impacts individual and aggregate outcomes. Heterogeneity in preferences toward debt and in dynamic optimization may generate important implications for the distribution of wealth that impact the efficacy of policy.

Laboratory experiments have the benefit of providing a controlled environment where researchers can clearly observe the causal effects of new and untried policies without having potentially detrimental real-world consequences. Unlike in the real world where we have only one long history, the same debt-deleveraging and policy response scenarios can be replicated with independent groups to evaluate the robustness of both behavior and policy. Compared to theory where agents' behavior is assumed, laboratory experiments allow subjects to bring their own home-grown preferences and biases into the environment.

Laboratory experiments often come with an important trade off: a sacrifice of some external validity in exchange for a gain in experimental control. As a matter of clearly discussing potential limitations of our research, we briefly discuss here what we believe are the two important potential threats to external validity: we must select a data-generating process (DGP) for our underlying economy and a subject pool to participate in our experiment. It is possible that our DGP does not map cleanly onto reality. It is also possible that our subjects do not behave in ways representative of typical economic agents.

Given our research question and design, we believe this trade off is minimal and worthwhile. Our experiments will involve financially-incentivized undergraduate students in the role of households making financial decisions for multiple generations. Undergraduate students in laboratory experiment have been shown to behave similarly with real world agents in markets, financial decision making, and in expectation formation (Kessler and Vesterlund, 2015, Cornand and Hubert, 2018). The data-generating process will be based on EMR's model, which has been a major advancement in capturing realistic inflation dynamics. That is, this design represents, arguably, a more realistic economic environment than, for example, environments where interest rates cannot remain permanently negative due to a representative discount factor. Our economic environment subsumes the inflationary and liquidity trap equilibria present in such models, while also allowing for a secular stagnation equilibrium to emerge.

4.1 Experiment

There are several goals for this experiment. First, we seek to establish whether secular stagnation equilibria emerge in an experimental economy driven by the combination of exogenous demand shocks and the real decisions of economic agents. Second, we test whether unconventional monetary policies such as raising the inflation target or eliminating the ZLB can effectively stimulate inflationary expectations and aggregate demand at the ZLB. Third, we test whether these unconventional policy can rescue economies from secular stagnation.

Each laboratory session - which is an independent economy - consists of 21 household agents that form price forecasts and budgetary decisions in a three-period overlapping generations framework. For simplicity, our design involves the automation of young and old households. The young decisions are completely automated to ensure that the young are maximally leveraged.[7] Each economy has seven undergraduate participants that make repeated budget decisions that influence the consumption outcomes of the 14 remaining middle-aged and old households.

The experiment consists of 50 periods (30 periods in our baseline treatment where an intervention is not introduced). Each period t consists of three stages.

Stage 1: All subjects simultaneously submit forecasts about the current price, $E_{i,t}P_t$ and subsequent period price, $E_{i,t}P_{t+1}$. Subjects also submit a qualitative forecast about the change in the nominal interest rate relative to the previous period (increase, stay the same, decrease). Subjects earn 2 points for correct qualitative interest rate forecasts and zero points otherwise. We incentivize price forecasts using the following payoff function:

$$ForecastPoints_t = 2^{-|E_t P_t - P_t|} + 2^{-|E_{t-1} P_t - P_t|} \tag{17}$$

[7] Small deviations in borrowing can produce drastically different inflation and output dynamics. In pilot experiments that did not involve automated young households, we found that subjects consistently underborrow during the early periods of their lifecycle (consistent with debt aversion observed by Meissner, 2016) which yields unstable, deflationary economies. We therefore automate this decision so that we create an experimental environment that allows us to test policy prescriptions aimed at alleviating secular stagnation etc.

Note that subjects can earn a maximum of 4 points per period for perfect price forecasts. Forecasting points for either forecast drop by one half for each lab dollar that a subject under or over forecasts. This is depicted graphically in Figure 4

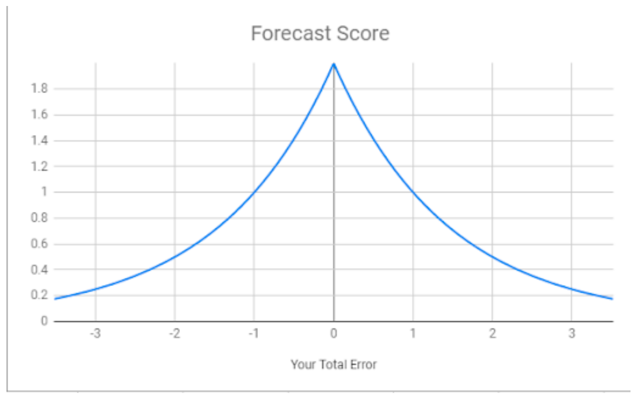


Figure 4: Payoff function for an individual price forecast

We elicit price and interest rate forecasts for various reasons. The efficacy of our policy interventions hinges critically on whether participants form model-consistent expectations. Price forecasts provide valuable insight into the relative importance of expectations in informing spending decisions. The median concurrent price forecast is also used to compute the expected income and interest rates participants are likely to face in the current period. We present this information to participants in the subsequent phase to facilitate their spending decisions.[8] While the qualitative interest rate forecast has no impact on how the economy evolves, it allow us to assess participants' comprehension of the central bank's policy rule.

Stage 2: Participants play the role of a middle-aged household who makes a consumption-saving decision after receiving predictions about their concurrent income, nominal interest rate, and concurrent and subsequent prices. Specifically, each participant makes a decision about how much of their current nominal income, $E_t Y_{i,t}$ to spend in period t. Any unspent income is automatically saved and consumed in the subsequent period when the agent becomes old.

Participants earn points based on their consumption decisions while middle-aged and old. We induce participants to behave as if they had a per-period utility function given by $U_t = 5 + ln(\alpha + C_t)$ where $\alpha = 0.00673$.[9] Since a participant is essentially two households at any

[8]We use a median price prediction rather than a weighted average price. This prevents subjects from coordinating expectations to manipulate prices in any favorable way. This also mitigates the ability of any one subject to significantly influence the economy via extreme expectations.

[9]This is a slight modification of the utility function to allow for the possibility that subjects consume zero output without facing exponentially negative payoffs. We select α such that $U(C_t) = 0$ when $C_t = 0$.

Period	Middle-Aged Household	Old Household (Automated)
1	Decision 1 (e.g. spend 40% / saving 60%)	
2	Decision 2	Decision 1 (e.g. spend remaining 60% + interest earned)
3	Decision 3	Decision 2
4	Decision 4	Decision 3
5	...	Decision 4

Figure 5: Co-determination of middle-aged and old spending

point in time (the middle-aged agent they are actively making a decision for in period t and the old-agent that they previously made a decision for in period $t-1$), they possess two separate utility functions.

Importantly, any money saved by a middle-aged household in period t will accrue interest at the prevailing nominal interest rate and be available to the same household in period $t+1$. This now-old household will spend all remaining wealth on output and the subject receives all utility from this consumption of output. The timing structure is depicted graphically in Figure 5.

After all participants have submitted their spending decision, we use all automated young agents and middle-aged participants' spending decisions in period t, as well as the remaining spending dollars of the period t old agents determined in period $t-1$, to compute total period t dollars for consumption spending. This information is used to clear markets, allocate output and assign utility. Subjects earn points based on how much of the consumption good (output) they purchase, on the accuracy of their price forecasts, and on the accuracy of their qualitative interest rate forecast.

Stage 3: The third phase is for participants to review the outcomes of the current period. All participants observe the total amount of output produced, price of output, nominal interest rate, as well as their own current spending decision and the amount of points earned from consumption.

We provide a history of all aggregate-level variables to all subjects in all periods (following the first period) during both stages of each period. Additionally, the central bank informs all subjects of its policy rule and its current inflation target during both stages of each period.

We convert experimental points into real dollars at a rate of 20-to-1. The use of monetary incentives in the experiment reflects the position of the economics profession that experi-

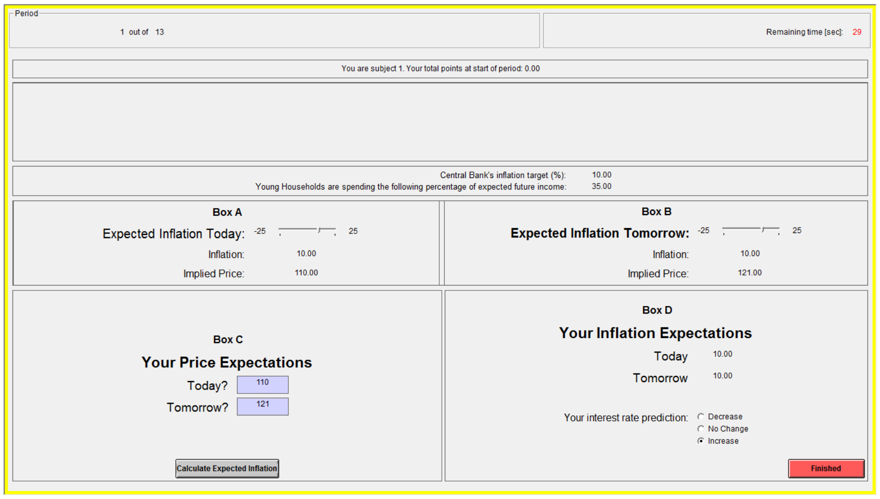


Figure 6: Stage 1 Screen

mental studies generalize to situations outside of the laboratory only if subjects' decisions have a direct and significant influence on their compensation.

We provide subjects with two tools to facilitate play. The first tool, available in Stage 1 of each period, allows subjects to convert inflation expectations into price expectations or to convert price expectations into inflation expectations. We do this so that subjects can easily incorporate both inflation and price information when forming price forecasts. The second tool, available in Stage 2, takes as inputs a subjects' price expectations and returns to them a suggested level of spending conditional on their individual price expectations. We note to subjects in our instructions that this suggested level of spending is conditional on their expectations and also inform them that they may enter any strictly positive number for their expectations. They are beholden to neither the price prediction provided in Stage 1 nor the median price predictions displayed to them on the Stage 2 screen. Finally, we also provide subjects with a full history of aggregate outcomes and individual decisions on all screens of the game. For examples, refer to the screen shots depicted in Figure 6 and Figure 7.

We face the non-trivial challenge of simultaneously clearing markets and allowing young agents to borrow from future uncertain income. EMR assume rational expectations to assuage these thorny issues. We follow their approach by relying on subject-provided expectations to provide income, price, and interest rate signals which can inform participants' decisions before markets are cleared. We couple subjects' expectations with a novel pricing algorithm to determine aggregate spending, price, wage, output, labor demand, and interest rate.

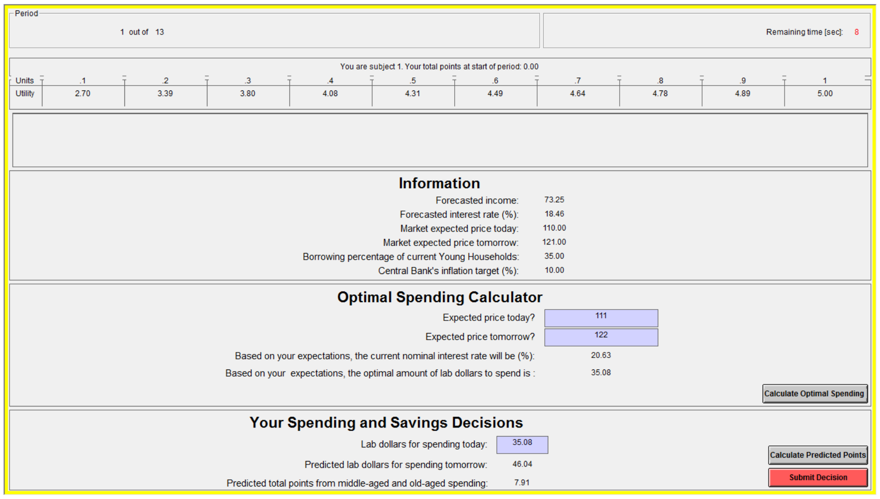


Figure 7: Stage 2 Screen

We develop and implement an algorithm built on numerical methods for solving the pricing equation. This is necessary because there is no analytical solution for prices, given the structure of this self-referential model. We solve for prices within our framework as follows:

For the program, we define the per-period, market-clearing price as:

$$P_t = \frac{C_Y + C_M + C_O}{Y_t}. \tag{18}$$

This gives us the following piece-wise, per-period price function:

$$P_t = \frac{C_Y + C_M + C_O}{Y^f}, \qquad \Pi \geq 1 \tag{19}$$

$$P_t = \frac{C_Y + C_M + C_O}{Y_t}, \qquad \Pi < 1. \tag{20}$$

We proceed by first supposing that prices are determined by Equation (20), which can be rewritten as

$$P_t = \frac{C_Y + C_M + C_O}{\frac{w_t}{P_t \alpha}^{\frac{\alpha}{\alpha - 1}}}. \tag{21}$$

Isolating P_t yields

$$P_t^{\frac{-1}{\alpha-1}} = \frac{C_Y + C_M + C_O}{\frac{w_t}{\alpha}^{\frac{\alpha}{\alpha-1}}}. \tag{22}$$

However, we know that per-period wages w_t are also a function of P_t since we have that

$$w_t = max(P_t\alpha\overline{L}^{\alpha-1},\ \gamma w_{t-1} + (1-\gamma)P_t\alpha\overline{L}^{\alpha-1}). \tag{23}$$

Substituting yields

$$P_t^{\frac{1}{\alpha}} = (C_Y + C_M + C_O)^{\frac{1-\alpha}{\alpha}} w_t\alpha^{-1} = C(\gamma(w_{t-1}) + ([1-\gamma]P_t\alpha\overline{L}^{\alpha-1}) \tag{24}$$

where

$$C = (C_Y + C_M + C_O)^{\frac{1-\alpha}{\alpha}}\alpha^{-1}.$$

Collecting prices, factoring, and making the following variable substitutions,

$$\begin{aligned} i. \quad & b = \frac{1-\alpha}{\alpha} \\ ii. \quad & A = C(1-\gamma)\alpha\overline{L}^{\alpha-1} \\ iii. \quad & B = C\gamma w_{t-1} \end{aligned}$$

,

yields

$$P_t[P_t^b - A] = B. \tag{25}$$

We solve this via the Newton-Raphson method of numerical approximation.

For example, suppose $f(P_t) = P_t^{b+1} - AP_t - B = 0$ and define an initial guess for our price as $X_0 = P_{t-1}$ and some stopping rule predicated upon meeting some minimum error rate ϕ. Then, if $f(X_0) \leq \phi$ the algorithm stops and $P_t \approx P_{t-1}$. Otherwise, if $f(X_0) > \phi$ the algorithm proceeds as follows:

$$X_1 = X_0 - \frac{f(X_0)}{f'(X_0)} = P_{t1}\frac{P_{t-1}^{b+1}AP_{t-1} - B}{(b+1)P_{t-1}^{b} - A}$$

Once the algorithm arrives at some X_i such that $f(X_i) \leq \phi$, define a temporary price as $P_t \approx X_i$.

Finally, we calculate output given this price and aggregate spending. If output exceeds potential then we know that our assumption that Equation (20) determines prices in a given period is incorrect, and the algorithm instead sets prices according to Equation (19).

Below we summarize how the Young, Middle-Aged, and Old households' spending decisions are computed.

The Young: We automate young households such that young household i in period t will automatically borrow a proportion $D_t^i \in [0, 1]$ of its middle-aged income. This is clearly problematic since the middle-aged income of these agents is not actually determined until markets clear in the following period. However, EMR's assumption of rational expectations circumvents this issue in theory. If subjects' expectations are rational, then there should be no difference in expected and realized prices. Thus, we compute the consumption expenditure of a Young household i in period t as $c_t^{i,y} = D_t^i E_t\{P_{t+1}\} = D_t^i E_t[Y_{t+1}^{i,m}]$.

The Middle-Aged: Subjects make budgeting decisions as Middle-aged households in stage 2 of each period. Subjects here have two considerations: a debt-repayment obligation incurred automatically by the household when young and a consumption/savings decision. However, our subjects face these considerations before income is actually determined. To deal with this, we suppose that the income of Middle-aged households is equivalent to the market expectation for current period prices. If we again suppose that we are in period $t = 0$ then middle-aged income is given as $E_0\{P_0\}$. Thus, a Middle-aged subject has net income $ni = E_0\{P_0\}c_1^j(1 + i_1)$. Suppose α_j is the proportion of net income allocated to savings so that $c_0^{j,m} = \alpha_j(E_0\{P_0\}c_1^j(1+i_1))$. We can then use $c_0^{j,m}$ for market clearing, which informs us how much money Middle-aged agents actually earn. One issue here is that if subjects systematically deviate from RE then we can have that $E_0\{P_0\} > P_0$ or $E_0\{P_0\} < P_0$. Because we have already cleared markets using a consumption level based on the market-expected price, we occasionally must adjust for deviations from RE by changing the amount of money that these middle-aged agents hold in savings for consumption while old. This is because deviations from RE (and from the correspond consumption/savings decision) can drive a wedge between expected and realized savings for middle-aged agents. If we call t expected savings of middle-aged agent j as $E_0\{s_0^{m,j}\}$ then $E_0\{P_0\} > P_0$ would cause $E_{j,0}\{s_0^{j,m}\} > s_0^{m,j}$ and opposite for the opposite case.

The Old: The decision for a given old household in period t is determined by the budgeting decision of a subject acting as a middle-aged household in period $t-1$. Old households automatically spend all remaining wealth on output. For example, if a subject i assigned a Middle-aged household in period $t-1$ instructs its household to save $s_{t-1}^{m,i}$ dollars then in period t that household will allocate $p_t c_t^{t,i} = s_{t-1}^{m,i}(1+i_{t-1})$ to consumption dollars.[10] Note then that subjects, anytime following period 1, earn consumption points from a currently-assigned Middle-aged household and an Old household. This Old household is the Middle-aged household assigned to that subject in the previous period.[11]

4.2 Treatments

We conduct a series of treatments to explore the learnability and stability of different equilibria with and without policy action. We initialize all sessions at the unique full-employment equilibrium where we assume, for steady-state values, that the economy is operating along the steady-state inflation path. A surprise exogenous deleveraging shock moves the borrowing constraint from $D = .35$ to $D^{shock} = .3$ [12] to create a unique secular stagnation equilibrium. Our interest is in the ability of different unconventional monetary policy actions to move the experimental economies out of secular stagnation and back to a full-employment equilibrium.

Monetary policy interventions include raising the inflation target (*HigherTarget*) and allowing a negative nominal interest rate (*NegativeIR*). Raising the inflation target generates multiple equilibria: a secular stagnation equilibrium, a liquidity trap equilibrium, and the targeted, high-inflation equilibrium. Removing the ZLB eliminates the upward sloping portion of the aggregate demand curve so that AD is fully describe by Equation (15). In theory, allowing for negative nominal rates can fully offset the deleveraging shock and stimulate aggregate demand sufficiently to recreate a unique inflationary equilibrium that coincides

[10]Here, c_t represents units of output and $s_{t-1}^{m,i}$ is the dollar amount saved by agent i in period $t-1$ while middle-aged.

[11]We automate Old households in period 1 based on the assumption that the economy moved along the steady-state inflation path in all periods before the start of our experiment.

[12]In our baseline treatment (*Baseline*), which does not feature a policy intervention, we set $D^{shock} = .28$.

with the central bank's inflation target. Finally, we include a fourth treatment (*NegativeIR-Portfolio*) wherein allow the central bank to set negative interest rates but also introduce a portfolio choice for subjects that allows subjects to hold savings as cash or bonds.

We use π^{tgt}, π^{ss}, π^{lt} to denote an inflationary steady-state equilibrium, a secular stagnation steady-state equilibrium, and a liquidity trap equilibrium, respectively.

4.2.1 *Baseline*

Baseline explores the ability of subjects to coordinate on the unique equilibria when they exist. This treatment features 30 periods of play divided into a 15-period pre-shock phase and a 15-period post-shock phase. The pre-shock phase features a unique equilibrium of π=10% with full-employment and output. This is followed by a deleveraging shock in period 16 that moves $D_t = .35$ to $D_t^{shock} = .28$, which creates a unique secular stagnation equilibrium of $\pi^{ss} = -24.4\%$ with labor rationing and output well below potential. We announce the deleveraging shock to subjects at the beginning of period 16 before the begin stage 1. This announcement informs subjects about the deleveraging shock, the magnitude of this shock, a brief explanation of how it impacts the economy, and informs subjects that the shock is permanent. Further, all subjects know that all other subjects know about the shock.

4.2.2 Policy treatments

Each subsequent treatment embeds *Baseline*, with the caveat that shocks in *HigherTarget* and *NegativeIR* are such that $D_t = .35$ to $D_t^{shock} = .3$.

HigherTarget: This treatment features 50 periods of play divided into three phases. The first two phases are fully described by *Baseline*. The third phase begins when the central bank announces the change to its inflation target in the beginning of period 30. The higher inflation target generates an environment with three equilibria: a secular stagnation, a liquidity trap, and a new targeted inflationary equilibrium. The policy intervention is announced on screen and aloud so that all subjects know that all subjects know about the policy change.

NegativeIR: This treatment again involves three phases where the first two phases are fully described by *Baseline*. Phases 3 begins following removal of the ZLB in period 30. Doing this removes the kink point in the AS curve, creating a unique, inflationary equilibrium that coincides with the central bank's inflation target. The policy intervention is announced aloud and accompanied by a single-page document that provides an example to help subjects understand the implications of negative interest rates.

NegativeIR-Portfolio: This treatment is equivalent to NegativeIR but includes a portfolio choice regarding how subjects store savings between periods. In this treatment, subjects can choose to hold all of their savings either as interest-bearing bonds or as cash. Subjects make this choice in the second stage of each decision period. To help subjects with this choice, we modify the optimal spending calculator to show subjects the expectations-optimal level of spending and saving for both portfolio choices.

The purpose of this treatment is to study whether subjects will opt out of bonds whenever rates become negative, which is akin to opting into ZLB conditions. A critical whole in the available, albeit it limited, observation data is household behavior in the face of negative savings rates. This is because commercial banks are hesitant to pass negative rates thru to consumers out of fear that households will simply choose to hold cash rather than subject themselves to negative rates. This treatment, to our knowledge, provides the first empirical evidence aimed at filling this hole in the observational data.

We summarize the treatment predictions in Table 1 below.

	Phase 1	**Phase 2**	**Phase 3**
Baseline	$\pi^{tgt} = 10\%$	$\pi^{ss} = -24.7\%$	N/A
HigherTarget	$\pi^{tgt} = 10\%$	$\pi^{ss} = -18.3\%$	$\pi^{tgt} = 30\%$, $\pi^{ss} = -18.3\%$, $\pi^{lt} = 16.7\%$
NegativeIR	$\pi^{tgt} = 10\%$	$\pi^{ss} = -18.3\%$	$\pi^{tgt} = 10\%$
NegativeIR+Portfolio	$\pi^{tgt} = 10\%$	$\pi^{ss} = -18.3\%$	$\pi^{tgt} = 10\%$

Table 1: Parameterized equilibria across treatments and phases

5 Results

We begin by providing a descriptive overview of aggregate results from the Baseline and three intervention treatments in Section 5.1 to Section 5.4. We then present the outcomes of formal hypothesis tests in Section 5.4.

5.1 *Baseline*

We first consider results from *Baseline* where we initialize our experimental economies with a unique targeted equilibrium and then introduce a deleveraging shock that depresses the spending of young households, thereby eliminating the targeted equilibrium and creating in its place a unique secular stagnation equilibrium. Results for this treatment are shown in Figure 8, which presents session-level (light blue lines, 8 sessions total) and treatment-level (dark blue lines) median outcomes for aggregate inflation, consumption, inflation expectations, output, and the nominal interest rate. All variables are displayed in percentage terms except for consumption, which we present as units demanded.

Note in Figure 8 that six of the eight experimental economies converge to the targeted steady-state equilibrium in Phase 1. Inflation is on average 10% and the output gap is closed by the end of Phase 1. This convergence is particularly impressive given that the overwhelming majority of subjects adopt a forecasting heuristic that involves updating as a function of recent economic outcomes.[13] Introducing the deleveraging shock consistently generates deflationary episodes, albeit of varying magnitude. Though two of our economies arguably converge to the secular stagnation equilibrium, we also observe a mix of both mild and moderate deflation in our remaining economies. Corresponding output gaps emerge, leading to real welfare losses for our experimental economies.

This lack of convergence to the secular stagnation equilibrium is due to a combination of a couple of factors. First, over-consumption occurs once subjects begin to experience deflation (Consumption sub-figure of Figure 8). This is roughly consistent with a Pigouvian effect (Patinkin, 1948), where deflationary episodes are quelled due to wealth effects generated by higher real wealth balances. Expectations also adjust sluggishly following the deleveraging shock, leading to further downward wage rigidity and a slower adjustment toward the secular stagnation equilibrium.

Interestingly, two of our experimental economies experience hyperinflation.[14] This is driven by a confluence of highly optimistic expectations and a few subjects vastly over consuming. This is perhaps surprising given that the central bank pursues an aggressive policy response to inflation. Because expectations remain relatively anchored through early periods of Phase 1 in these sessions – despite increasing inflation rates – we eventually see that pursuing a Taylor-type rule reinforces this inflationary pressure (i.e. increasing the interest rate exacerbates runaway inflation). The lack of responsiveness of the economy to the high interest rate suggests that the wealth effect strongly dominates the substitution effect for participants.

Overall, results from *Baseline* indicate that we are able to successfully implement the EMR theoretical framework in an experimental laboratory setting. Though not all economies converge fully to the secular stagnation steady-state equilibrium following the deleveraging

[13]We discuss forecasting heuristics for both nowcasts and forecasts in detail in **??**.

[14]We truncate these sessions in the Inflation sub-figure of Figure 8 due to scaling issues.

Baseline Results

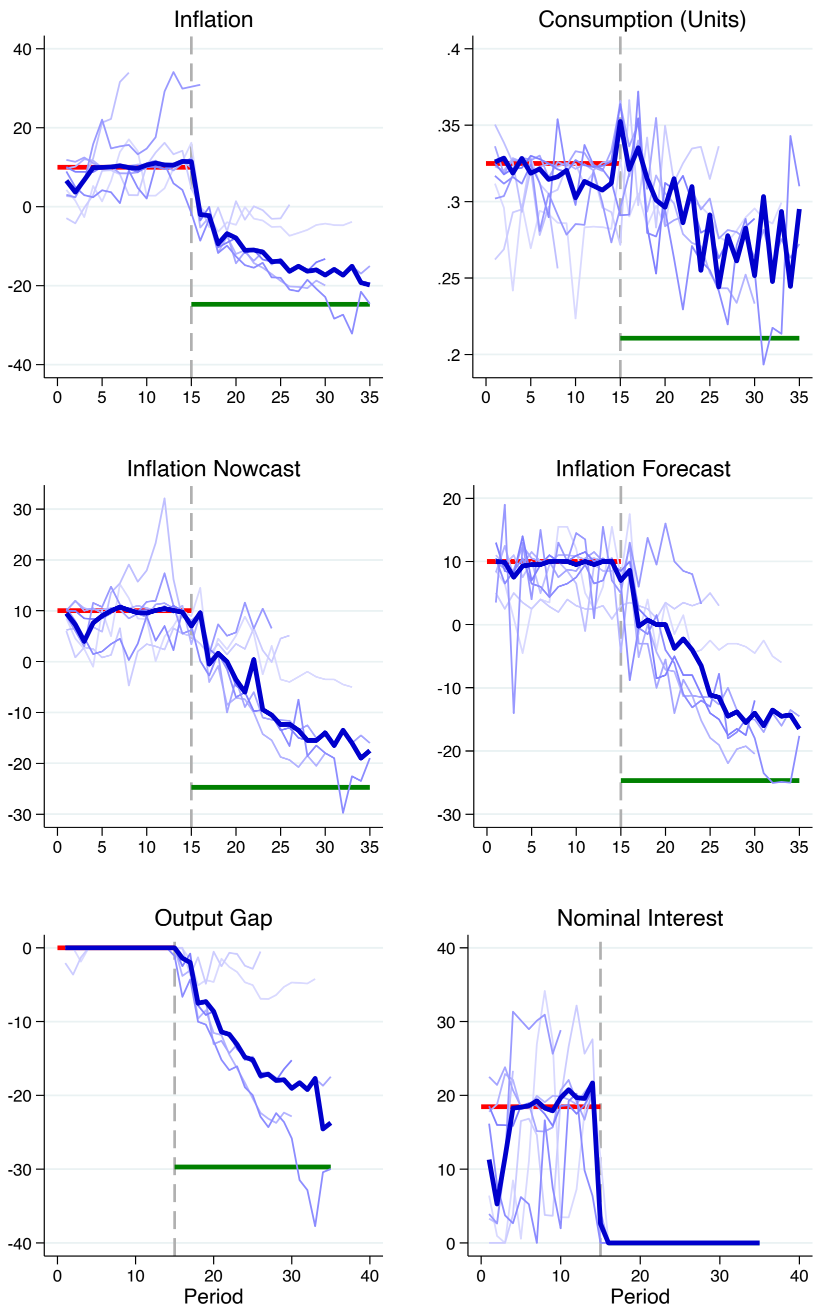


Figure 8: This figure summarizes results for *Baseline*. Light-blue lines represent session-level medians (where appropriate) and the thicker, dark-blue lines represent treatment-level medians (where appropriate). All data is given in percentage terms except for consumption, which is displayed in units demanded. Nowcast and Forecast refer to current-period and one-period-ahead inflation expectations, respectively. Colored horizontal lines denote steady-state equilibrium values and vertical dashed lines denote the point of transition from phase 1 to phase 2 in the experiment. Red equilibrium lines correspond to the targeted, full-employment equilibrium and green lines to the secular stagnation equilibrium.

shock, we do consistently create economic conditions that warrant intervention by generating deflation, consumption shortfalls, and output gaps.

5.2 *HigherTarget*

We now consider results from *HigherTarget*, which nests *Baseline* but also includes an intervention phase (phase 3) where the central bank addressed secular decline by permanently increase its inflation target. The intuition for this intervention is that permanently increasing the central bank's inflation target should stimulate forward-looking inflation expectations, thereby increasing aggregate demand and closing the output gap. Additionally, coordinating expectations on a higher target can increase expected wages, which should also stimulate aggregate demand.

Increasing the central bank's inflation target does not eliminate the secular stagnation equilibrium but instead adds both a full-employment and a liquidity trap equilibrium. The ability to discern among this multiplicity of equilibria highlights one of many strengths of using an experimental approach in macroeconomics. Tightly-controlled, repeated experimentation can give insight about equilibrium selection problem even when theory cannot.

We show the results from *HigherTarget* in Figure 9. Similar to *Baseline*, subjects in *HigherTarget*converge to the targeted equilibrium in phase 1 and the deleveraging shock consistently generates pessimistic expectations, generates deflation ranging from mild to severe, and opens output gaps that mimic the magnitude of deflation. This creates an interesting setting where we can test the efficacy of our policy intervention at addressing secular declines of various magnitude.

We find that, regardless of the severity of the deflationary trap, permanently increasing the central bank's inflation target fails to restore aggregate dynamics in our experimental economies to the targeted steady state equilibrium values. Instead, we observe in most economies that inflation exhibits an underwhelming response to the new inflation target. Further, we see that session-level inflation expectations never re-coordinate on the central bank's new targeted equilibrium. In fact, it is only for a single experimental economy that the session-level inflation forecast reaches the targeted equilibrium. However, this happens only briefly and, in each instance, is followed by a quick collapse. This inability to generate sufficiently inflationary expectations, coupled perhaps with the Pigovian effects discussed in *Baseline*, lead to a treatment-level average consumption that falls well short of the targeted equilibrium level of consumption. This shortfall of inflation, inflation expectations, and

HigherTarget Results

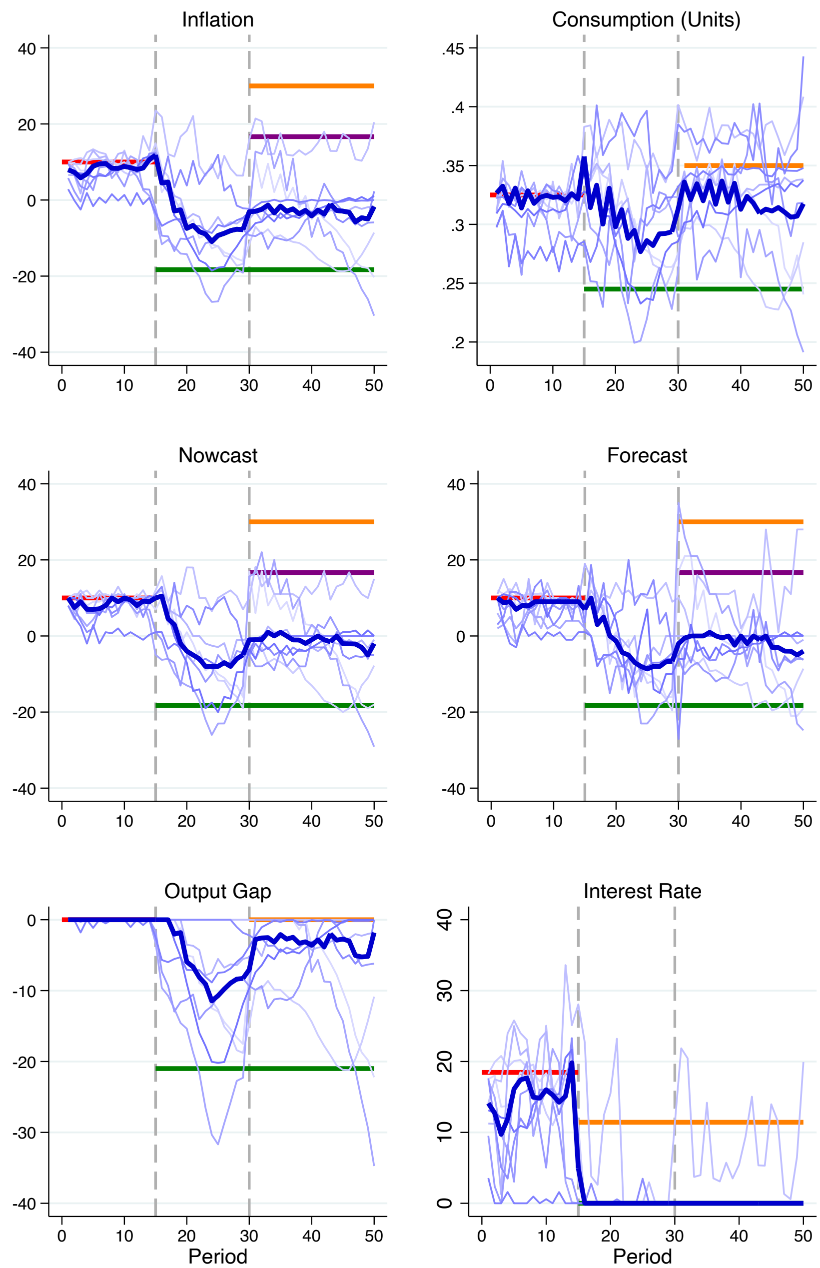


Figure 9: This figure summarizes results for *HigherTarget*. Light-blue lines represent session-level medians (where appropriate) and the thicker, dark-blue lines represent treatment-level medians (where appropriate). All data is given in percentage terms except for consumption, which is displayed in units demanded. Nowcast and Forecast refer to current-period and one-period-ahead inflation expectations, respectively. Colored horizontal lines denote steady-state equilibrium values and vertical dashed lines denote the point of transition between phases in the experiment. Red and green horizontal lines again denote targeted and secular stagnation equilibria, purple horizontal lines denote the liquidity trap equilibrium, and orange horizontal lines denote the targeted equilibrium that corresponds to the central bank's higher inflation target in phase 3.

consumption leads to a persistent output gap in most economies. In those few economies where the output gap does close in phase three, reprieve is only fleeting.

The confluence of these things - the inability to coordinate expectations and consumption on the targeted equilibrium values, to generate sufficient aggregate inflation, and to consistently close the output gap - leads us to conclude that permanently increasing the inflation target is not a promising intervention into secular stagnation. The obvious question then is why does this intervention fail? The answer - subjects in *HighterTarget* economies do not perceive the increased inflation target as credible.

To see this, we highlight two important facts that emerge from our data. First, subjects in these economies know very well the central bank's original inflation target. We highlight this inflation target in our instructions, display this inflation target on screen in each period, and remind subjects of this target in a summary screen at the end of each decision period. Thus, any wedge between this target and prevailing aggregate inflation during phases 1, 2 is salient for our subjects. This means that subjects are quite aware that our mechanistic central bank is unable to achieve its initial inflation target.

Second, subjects in these experimental economies understand and internalize that the zero lower bound is a binding policy constraint for our mechanistic central bank. Qualitative interest rate forecasts are generally accurate, indicating that subjects understand the relationship between inflation and interest rates. The accuracy of these forecasts increases significantly whenever economies arrive at the ZLB, with most subjects guessing that the central bank will remain at the ZLB.[15]

Thus, subjects in these economies see a policy-constrained bank that has been unable to achieve a given inflation target drastically increase its inflation target without somehow increasing its policy space.

It is worth noting that several *HigherTarget* economies in the post-intervention environment do manage to mitigate deflation by coordinating loosely on zero inflation. This is true despite there no stable price equilibrium among the set of predicted rational expectations equilibria.[16] Coordination on zero-percent inflation has the effect of trivializing price forecasts for subjects and greatly reducing the complexity of the two-period optimization problem subjects face in stage 2 of each period.

The shortcoming of aggregate inflation that we observe in *HigherTarget* matches the observed

[15]We provide a more detailed discussion of these qualitative forecasts by treatment and phase in **??**.
[16]In fact, EMR point out that such a steady-state is impossible in their model.

response of inflation in Japan following the Bank of Japan's (BoJ) attempt in January 2013 to address persistent deflation by doubling its own inflation target from 1 to 2% (see Figure 10). Though the BoJ's increase in the inflation target may have been insufficient (i.e. they fell prey to the 'timidity trap' discussed earlier), our results suggest that the intervention may have have also failed simply because it wasn't credible. That is, the BoJ may have taken a sufficiently strong policy action that failed because persistent deflation preceding the intervention preemptively undermined the intervention.

More generally, our results suggest policy interventions that depend critically on directly manipulating inflation expectations to offset secular decline may be ineffective because the economic conditions that eventually compel the central bank to implement such an intervention may also erode credibility such that the intervention is ineffective.

5.3 *NegativeIR*

This subsection considers results from *NegativeIR*. This treatment differs from *HigherTarget* in that the mechanistic central bank now intervenes into deflationary traps by implementing negative nominal interest rates rather than by increasing its inflation target. Crucially, the efficacy of this intervention does not hinge on the expectations channel. Rather, negative nominal interest rates threaten to erode real wealth and therefore encourage more present-period consumption. This increase in present-period consumption should immediately increase inflation via its impact on aggregate demand.[17] Increased inflation should lead to higher inflation expectations. These two effects - increased inflation coupled with increased inflation expectations - should become reinforcing.

We can also highlight the difference between these interventions by considering the relationship between inflation expectations, inflation, and consumption in each treatment. Inflation expectations should react immediate to the central bank's inflation target in *HigherTarget*, which leads in increased consumption and increased inflation. However, increased consumption leads to increased inflation and this leads to increased inflation expectations in x*NegativeIR*.

Results from *NegativeIR* are shown in Figure 11. First, note that implementing negative interest rates does not lead to the same equilibrium selection problem as does increasing the central bank's inflation target. Instead, removing the zero lower bound removes the kink

[17] Supply in this economy is constrained by the size of the middle-aged cohort. Whenever supply is at capacity, increased spending necessarily leads to increased inflation. If production isn't at capacity, then spending in excess of whatever restores full production leads to inflation.

Inflation and Inflation Target in Japan

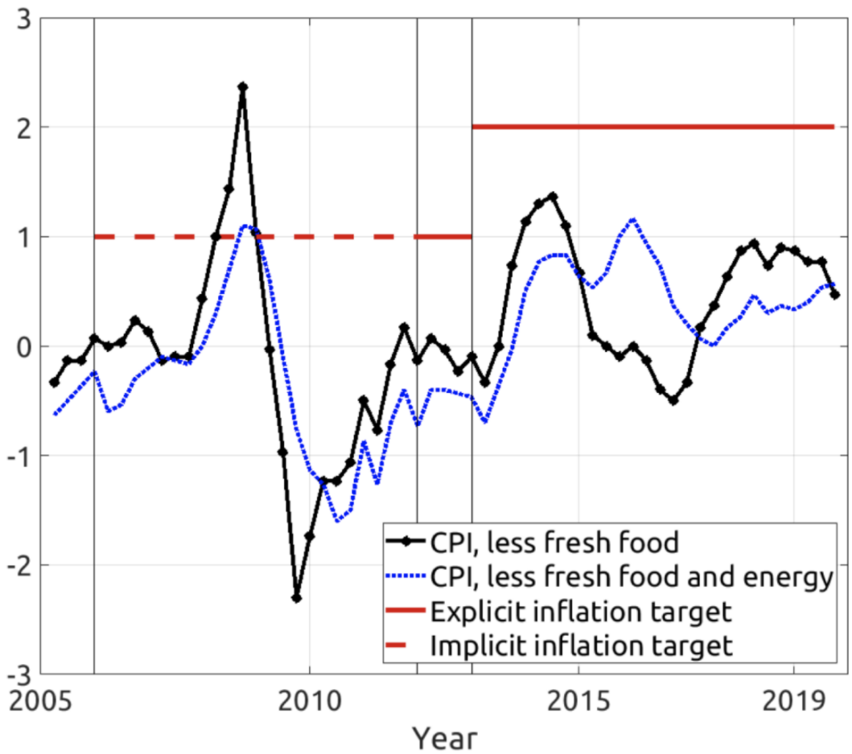


Figure 10: This figure and corresponding information are borrowed from Nakata (2019). This figure shows two configurations of CPI inflation from Japan following the Bank of Japan's (BoJ) attempt to address persistent deflation via a permanent increase in its Inflation target (solid red line) in January 2013 (third vertical line). Similar to what we observe in our experimental economies in *HigherTarget*, this policy intervention achieves only a mild response that falls well short of the higher inflation target. Note that Japan's inflation target was implicit up to February of 2012 (dashed red line).

NegativeIR Results

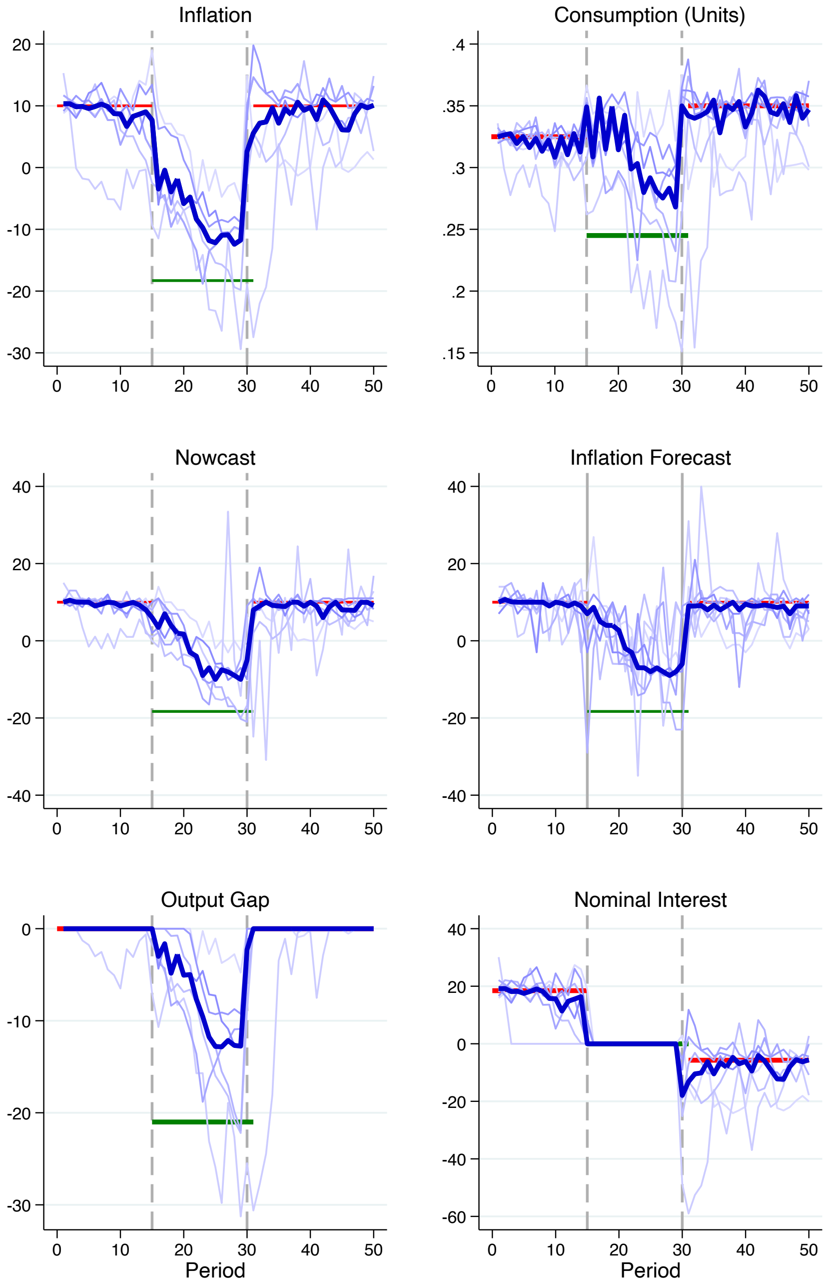


Figure 11: This figure summarizes results for *NegativeIR*. Light-blue lines represent session-level medians (where appropriate) and the thicker, dark-blue lines represent treatment-level medians (where appropriate). All data is given in percentage terms except for consumption, which is displayed in units demanded. Nowcast and Forecast refer to current-period and one-period-ahead inflation expectations, respectively. Colored horizontal lines denote steady-state equilibrium values and vertical dashed lines denote the point of transition between phases in the experiment. Red and green horizontal lines again denote targeted and secular stagnation equilibria.

in the aggregate demand curve, thereby eliminating the secular stagnation equilibrium and restoring the unique targeted equilibrium present in phase one of each treatment (as depicted in Figure 3). As was true with experimental economies in *Baseline* and *HigherTarget*, we again observe converge in phases 1 and 2 to the targeted and secular stagnation equilibria, respectively. Deleveraging shocks generate deflationary episodes with now-familiar session-level heterogeneity in the magnitude of deflation.

Now when the central bank intervenes, we see in Figure 11 that our economies converge to the targeted equilibrium. As one might expect, we see a sharp increase in consumption, which generates considerable inflation in the period immediately following the policy intervention. Interestingly, we also see that both the nowcast and forecast of inflation also respond to the announcement of the central bank's decision to use negative nominal interest rates. This further supports the idea that intervention in *HigherTarget* fails precisely because intervention there doesn't increase the policy space. Finally, we see that this implementing negative nominal rates also consistently closes output gaps that emerged during phase two if our *NegativeIR* sessions. This closure is both immediate and stable for all but a single experimental economy.

Also interesting here are phase three consumption dynamics in *NegativeIR* relative to *HigherTarget*. Excluding the single economy in *NegativeIR* that does not eventually achieve the central bank's inflation target, we see that cross-sectional, session-level consumption heterogeneity in phase three of *NegativeIR* is significantly lower than in the *HigherTarget*, which suggests that the ability of *NegativeIR* to re-coordinate expectations on the bank's inflation target also has the effect of stabilizing consumption. Because consumption is mostly expectations-consistent, reducing cross-sectional disagreement in expectations also reduces the cross-sectional dispersion of consumption and savings.

5.4 Negative interest rate intervention with a portfolio decision

A reasonable concern is that the ability of negative policy rates to pull economies out of deflationary traps in *NegativeIR* might depend on the lack of portfolio choice. However, a common real-world concern is that if commercial banks pass negative rates thru to consumers then those consumers will opt to hold cash rather than endure negative savings rates. If true, the absence of portfolio choice in *NegativeIR* poses a challenge to the external validity of our results. To address this concern, we implement *NegativeIR+Portfolio*, which is identical to *NegativeIR* but allows subjects to transfer wealth between periods by holding either interest-bearing bonds or cash. Introducing a portfolio choice allows for real-world concerns like cash hording that might mute the effectiveness of negative nominal rates.

However, we are agnostic about how introducing this portfolio choice would change our results relative to *NegativeIR*. On one hand, negative savings rates are quite salient for subjects and make the opportunity to hold cash rather than bonds whenever rates are negative appealing. If subjects do hold cash, this is akin to selecting back into the zero lower bound where only the secular stagnation equilibrium exists. This sort of concern is at least part of why commercial banks in the Euro area did not pass negative rates thru to household deposit rates whenever the ECB implemented negative nominal interest rates in the Euro area.We discuss this in more detail in Section 8.

On the other hand, subjects may also understand that negative rates are a 'necessary evil' that prevent deflation and an output shortfall. Further, the economic instability inherent in such circumstances increases the complexity of inflation forecasting and in solving the two-period optimization problem. Thus, subjects may choose to endure negative interest rates if they think it is favorable to sacrifice some per-period net wealth in exchange for increasing available output in each period and for potentially reducing the complexity of both incentivised tasks. It is easy to think of real-world analogs for this sort of logic. People in the real-world may be willing to endure negative rates whenever they perceive the alternative as a deep, protracted recession or economic collapse. That is, people may view negative rates as a short- or medium-term trade off that restores long-term economic stability and growth. Additionally, there are obvious mechanical reasons - like the inconvenience that comes with using only cash to spend - that may also contribute to a real-world tolerance of negative rates.

Results from *NegativeIR+Portfolio* are shown in Figure 12. Before discussing results, we first note key differences between *NegativeIR* and *NegativeIR+Portfolio*. First, the added complexity of the portfolio choice leads to less stability in early periods of play in phase 1. Because of this, we do not see the customary convergence to in phase one and we observe particularly severe deflation in several economies in phase 2.

That said, results from *NegativeIR+Portfolio* overwhelmingly indicate that negative nominal rates are robust to portfolio choice. Introducing negative nominal rates leads to an almost immediate convergence to the targeted equilibrium. this is true despite the very severe deflation experienced in many of our economies in phase 2. Despite the increased session-level disagreement relative to *NegativeIR*, we also see that introducing negative rates still coordinates treatment-level median nowcasts and forecasts at the central bank's targeted equilibrium. Interestingly, we also see that the treatment-level median interest rate is quite

NegativeIR+Portfolio Results

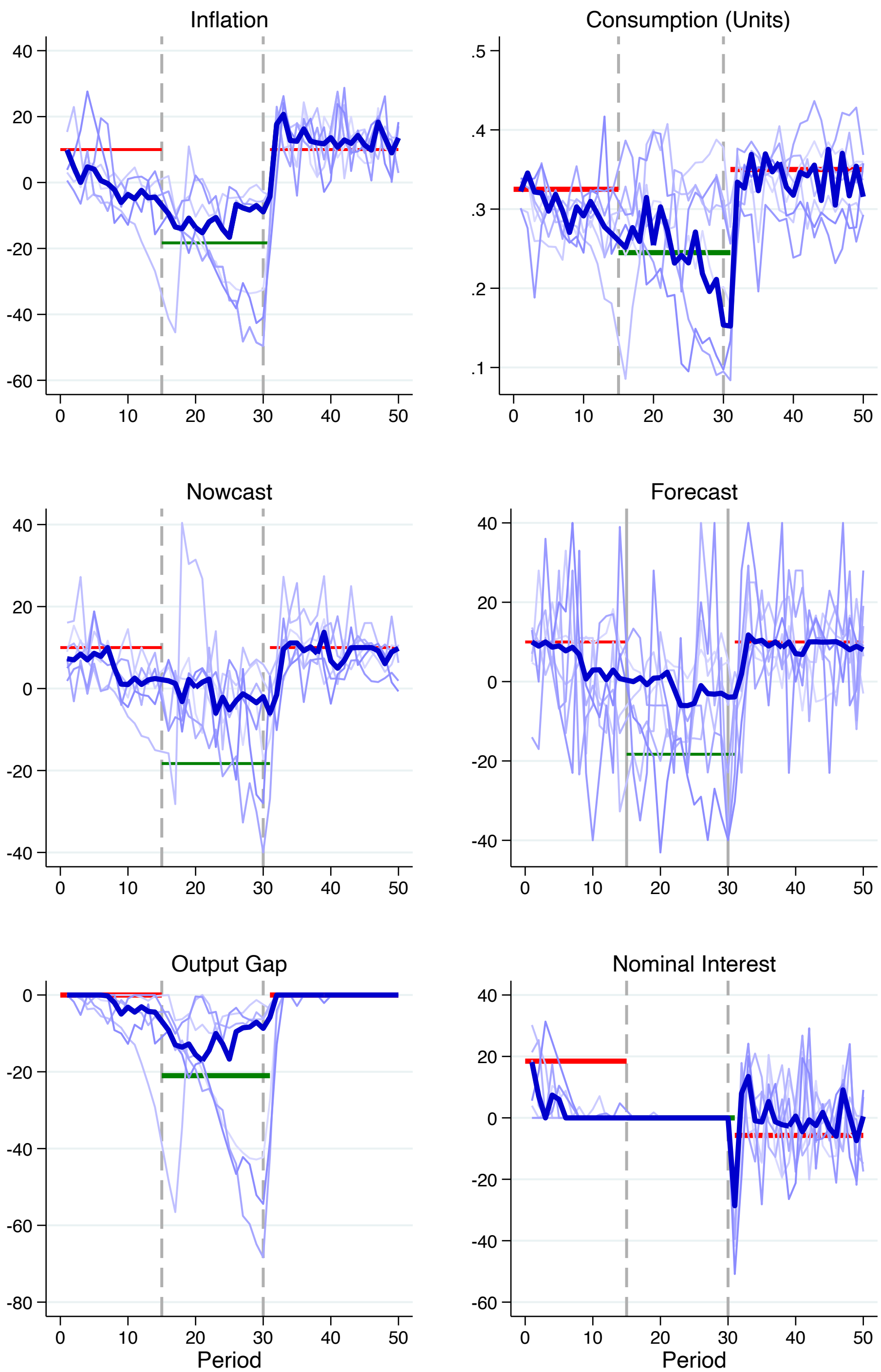


Figure 12: This figure summarizes results for *NegativeIR+Portfolio*. Each thin line represents data averaged across individuals for a single session. Thick lines treatment medians. For the second sub-figure depicting expectations, solid lines are session-level median nowcasts and dashed lines are session-level median forecasts.

often positive or non-zero in phase 3. This is likely due to the oscillatory pattern we observe in consumption leading to the corresponding spikes we see in inflation, which prompts our mechanistic central bank to increase rates to reduce inflation to its target.

Convergence

We now evaluate the convergence of the economies, for each phase, to the predicted equilibria. In Phase 1, the predicted steady-state inflation rate is 10%. We fail to reject H1 that inflation reached this level in *Baseline* and *NegativeIR* (Wilcoxon signed rank tests, $p = 0.26$ (N=8) in *Baseline*, $p = 0.13$ (N=7) in *NegativeIR*.) In *HigherTarget*, inflation is slightly but significantly above the equilibrium at 13.2% ($p = 0.05$, N=9).

We hypothesized in H2 that large deleveraging shocks would inflation to stabilize at the secular stagnation equilibrium. We compare the mean inflation in the final five periods of Phase 2 to the equilibrium prediction of -24.4% inflation (in sessions that reached period 25). We reject H2 that the economies have converged to the secular stagnation equilibrium (Wilcoxon signed rank tests, $p = 0.03$ (N=6) in *Baseline* , $p = 0.008$ (N=9) in *HigherTarget*, and $p = 0.018$ (N=7) in *NegativeIR*.)

We also hypothesized that raising the inflation target to a sufficiently high level will move an economy to the targeted inflationary equilibrium of 30%. We compute the mean inflation in Phase 3 of *HigherTarget* after period 40. Mean inflation in Phase 3 after period 40 is -4.3%. We reject H3 that the economies converge to the new target inflationary equilibrium (Wilcoxon signed rank test, $p = 0.018$ (N=7)).

Finally, we hypothesized that eliminating the ZLB would return the economies in *NegativeIR* to their targeted inflationary equilibrium of 10%. Again, we compute the mean inflation in Phase 3 of *NegativeIR* after period 40. Across all sessions, mean inflation is 8.01%. We fail to reject H4 that the economies converge to the original inflationary equilibrium (Wicoxon signed rank test, $p = 0.31$ (N=7)).

6 Unconventional Monetary Policy and Expectations

Next, we can assess how the shocks and policy interventions alter subjects' nowcasting and forecasting heuristics. The different heuristic models we consider are listed below in Table 2.

The first three heuristics are associated with rational expectations equilibria, depending on the phase of the experiment. M1 Target assumes that a subject bases her price forecast on the

Model Class	Heuristic Name	Model
M1	Target Equilibrium	$E_{i,t}\pi_t = E_{i,t+1}\pi_{t+1} = \pi^{tgt}$
M2	Liquidity Trap Equilibrium (LT)	$E_{i,t}\pi_t = E_{i,t+1}\pi_{t+1} = \pi^{lt}$
M3	Secular Stagnation Equilibrium (SS)	$E_{i,t}\pi_t = E_{i,t+1}\pi_{t+1} = \pi^{ss}$
M4	Constant Gain (CGL)	$E_{i,t}\pi_t = E_{i,t-1}\pi_{t-1} - \gamma_i(E_{i,t-1}\pi_{t-1} - \pi_{t-1})$ $E_{i,t+1}\pi_{t+1} = E_{i,t-2}\pi_{t-1} - \gamma_i(E_{i,t-2}\pi_{t-1} - \pi_{t-1})$
M5	Trend-chasing (Trend)	$E_{i,t}\pi_t = \pi_{t-1} + \tau_i(\pi_{t-1} - \pi_{t-2})$ $E_{i,t+1}\pi_{t+1} = E_{i,t}\pi_t + \tau_i(E_{i,t}\pi_t - \pi_{t-1})$
M6	Naive Inflation (Naive Pi)	$E_{i,t}\pi_t = \pi_{t-1}$ $E_{i,t+1}\pi_{t+1} = E_t\pi_t$
M7	Naive Price	$E_{i,t}\pi_t = E_{i,t+1}\pi_{t+1} = 0$

Table 2: Nowcasting and forecasting heuristics

assumption that inflation today will equal the central bank's inflation target. M2 Liquidity Trap (LT) assumes that subjects forecast according to the liquidity trap equilibrium while M3 Secular Stagnation (SS) assumes that subjects forecast according to the secular stagnation equilibrium. M1 is ex-ante rational in Phases 1 and 3 of all treatments. M2 is ex-ante rational in Phase 3 of *HigherTarget*, and M3 is ex-ante rational in Phase 2 of all treatments and Phase 3 in *HigherTarget and NegativeIR-Portfolio.*

M4 Constant Gain Learning (CGL) assumes that a subject forms an inflation forecast today by updating their most recently forecasted and observed inflation expectation based on their most recent forecast error. In the case of their period t nowcast, we assume they update their previous period's nowcast about period $t-1$ based on their most recent error, which would be observed at the beginning of period t. For their period $t+1$ forecast, we assume they use their most recent one-period ahead forecast performance to update their past forecast. Specifically, they would update their period $t-2$ forecast about period $t-1$ according to error, which would be observed at the beginning of period t. Given these formulations, we consider a range of parameterizations of $\gamma \in [0.1, 1.5]$.

M5 Trend-chasing assumes that a subject's inflation nowcast and forecast are an extrapolation of yesterday's inflation based on the recent trends in inflation. In particular, the period t nowcast will be extrapolated based on the change in inflation between $t-2$ and $t-1$. The period $t+1$ forecast will use the period t nowcast as the anchor, and the extrapolation is based on the difference between $t-1$ inflation and their nowcast about period t inflation. Given these formulations, we consider a range of parameterizations $\tau \in [0.1, 1.5]$.

M6 Naive Inflation assumes that a subject bases both her period t nowcast and $t+1$ forecast on the assumption that inflation will equal period $t-1$ inflation. Finally, M7 Naive Price assumes that a subject forms their inflation nowcast and forecast assuming no change in prices, i.e. inflation of zero.

We classify a subject by comparing, in each period, her inflation nowcast and forecast for today to the predictions arising from each of M1-M7. We then calculate the mean absolute error for each hypothetical heuristic (and for each parameter value for M4 and M5) and classify participants as belonging to the heuristic that has the minimum MSE.[18]

EMR's policy prescription to raise the inflation target in response to secular stagnation demands a strong expectations channel of monetary policy to work optimally. Gibbs (2017) has since shown that the targeted equilibrium predictions of EMR are e-stable and thus survive under a form of least squares learning.

Phase 1

We observe relatively consistent heuristics in Phase 1 across the four treatments. Participants use a mix of nowcasting approaches, with Trend-chasing followed by Target being the most prevalent heuristics. The exception is in *NegativeIR-Portfolio* where more than one-third of participants are best classified as constant gain learning and approximately 18% of participants nowcast zero inflation. The increased heterogeneity and usage of naive price nowcasting heuristics in *NegativeIR-Portfolio* reflects the relatively greater cognitive complexity and endogenous volatility associated with the environment.

Participants use notably different heuristics for their one-period ahead inflation forecasts. In all treatments, we observe a larger proportion of participants anchor their inflation forecasts on the central bank's inflation target or on the previous period's inflation. This reliance on focal inflation information is indicative of increased cognitive challenge in forming longer-term forecasts and is characteristic of surveyed longer-term expectations that tend to be more effectively anchored than shorter-term expectations.

[18] Note that the nowcasting heuristic M4 is equivalent to M6 for $\gamma_i = 1$. In the case that participants were classified in both, we assign their type to be M6 Naive Inflation.

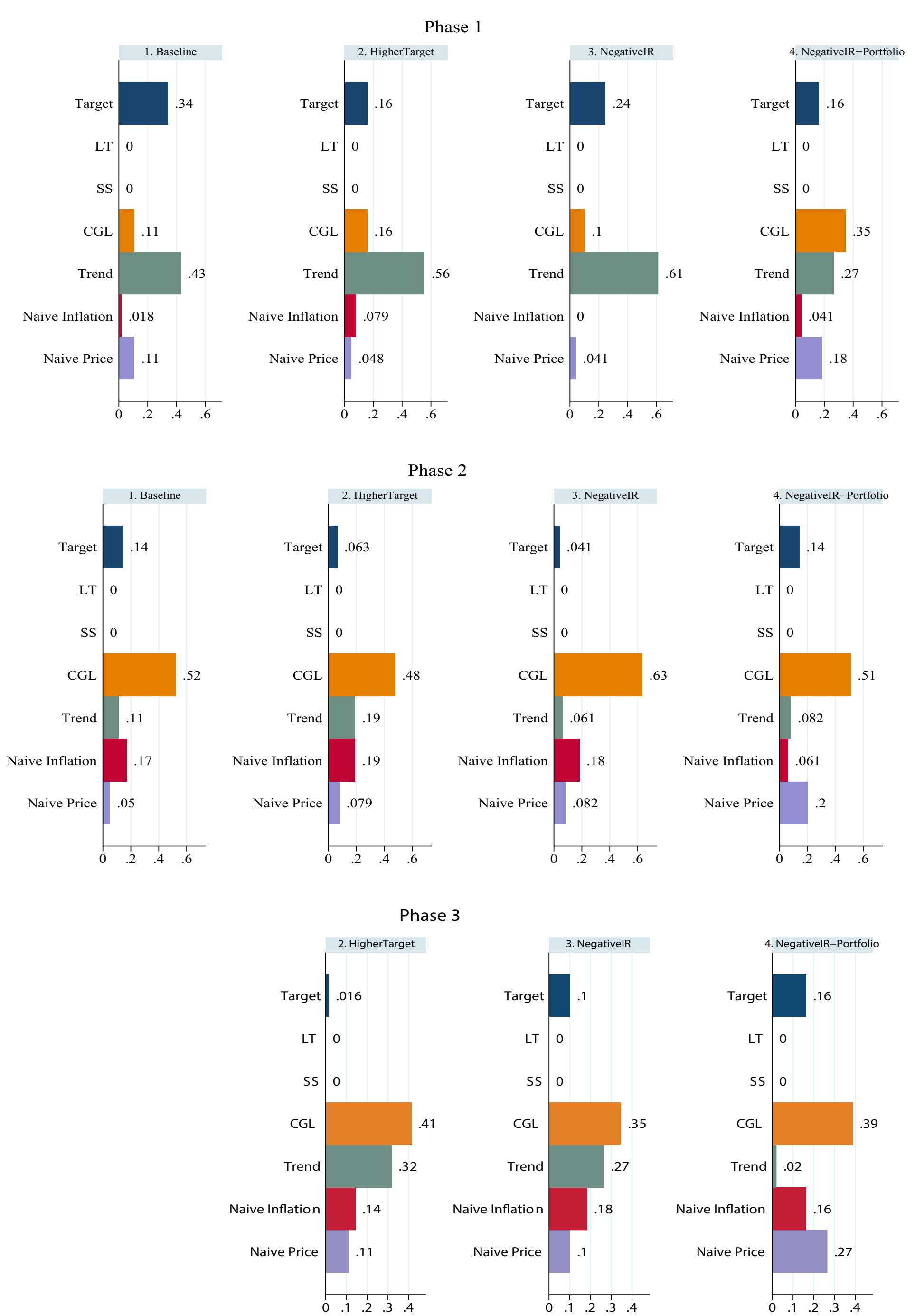


Figure 13: Nowcasting heuristics, Period t inflation, by phase and treatment

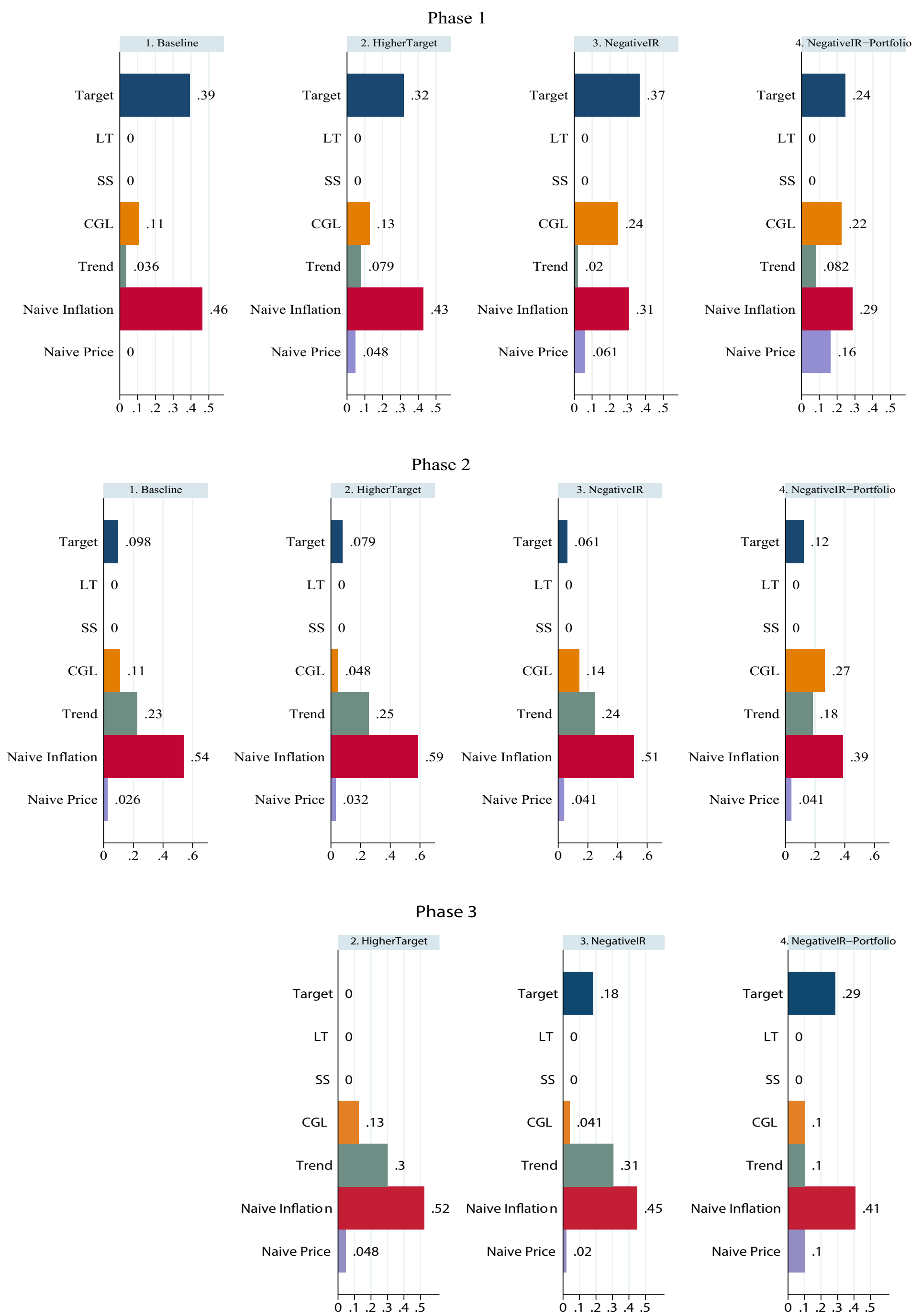


Figure 14: Forecasting heuristics, Period $t+1$ inflation, by phase and treatment

Phase 2

The deleveraging shock at the beginning of Phase 2 generates significant heterogeneity in heuristics, with all five classes of heuristics represented. Usage of the central bank's target declines in all treatments (from 34% to 14% in *Baseline*, 16% to 6% in *HigherTarget*, 24% to 4% in *NegativeIR*, and 16% to 14% in *NegativeIR-Portfolio*. This decrease in M1 Target heuristic is rational as the target is no longer an equilibrium outcome. Note that neither the liquidity trap or secular stagnation equilibria are focal points for participants. This is because we did not inform them of these equilibrium values. Nonetheless, participants' expectations do not adjust in line with these equilibria. The relatively minimal adjustment in *NegativeIR-Portfolio* away from the M1 heuristic is further evidence that participants were more cognitively taxed in this treatment and relied heavily on focal information even when it was no longer relevant.

M4 Constant-Gain Learning heuristic becomes the dominant nowcasting heuristic as participants grapple with making predictions in an unfamiliar environment. This comes at a significant reduction in the Trend-chasing heuristic.

Participants' one-period ahead inflation forecasts also shift away from anchoring on the inflation target toward more backward-looking expectations such as M5 Trend-Chasing and especially M6 Naive Inflation.

Phase 3

Increasing the inflation target to 30% in Phase 3 does not increase the share of participants using the central bank's target to form their nowcast (the share falls from 6% in Phase 2 to less than 2% in Phase 3). Likewise, no participant perceived the central bank's new inflation target of 30% as credible when forming their one-period ahead inflation forecast. The distributions of nowcasts and forecasts do not change in a meaningful way between Phase 2 and Phase 3, suggesting that increasing the central bank's inflation target did not significantly effect how participants perceived their environment.

When the central bank eliminates the ZLB in *NegativeIR* more participants are willing to utilize the central bank's 10% inflation target as their nowcast (increase from four to 10%) and forecast (six to 18%). In other words, negative interest rates are effective at generating more credibility in the central bank. Participants also rely less on constant gain learning and naive inflation to formulate their forecasts in favour of trend-extrapolation. We observe a qualitatively similar pattern in *NegativeIR-Portfolio*, albeit a more muted response in heuristics to the policy intervention. Credibility in the target is even higher in Phase 3 than in Phase 1, suggesting that negative interest rates generated sufficient inflationary pressures to improve anchoring on the central bank's inflation target.

7 Why do negative rates but higher targets fail?

This section summarizes why permanent increases in the central bank's inflation target fail to pull economies out of deflationary traps but implementing negatives rates - even in the presence of portfolio choice - does not. To aide in this discussion, we include Figure 15, which focuses on treatment-level effects of policy treatments for the five periods before and ten periods after the policy intervention.

We start with *HigherTarget*. In theory, successful intervention in this treatment requires the new inflation target to coordinate the expectations of forward-looking, dynamically optimizing agents. However, this policy action does not eliminate the secular stagnation equilibrium because agents do not necessarily expect the ZLB to become non-binding in the future.[19] A breakdown of any of these three necessary condition (forward-looking expectations, coordinating expectations on the higher target, or expectations-consistent real decisions) will prevent economies from converging to the full-employment equilibrium.

This means that we need to know which of the necessary conditions break down in *HigherTarget* in order to understand why increasing the inflation target fails in our experimental economies. Do subjects make real decisions consistent with their expectations? Yes. We show this in Figure 16, which depicts deviations from expectations-consistent consumption decisions expressed in percentage terms. Though there is considerable consumption heterogeneity, the mean treatment-level deviation from expectations-consistent consumption is never statistically indistinguishable from zero.

Does the intervention in *HigherTarget* coordinate expectations on the target? No! As discussed in Section 5.2 (and depicted in Figure 9), neither inflation nowcasts or forecasts re-coordinate on the central bank's inflation target. Why not? Because subjects in our experiment overwhelmingly employ backward-looking forecasting heuristics (see Figure 13). The majority of subjects in *HigherTarget* form expectations using trend extrapolation in

[19] As discussed by EMR, this is different from models of temporary liquidity traps (Krugman, 1998; Eggertson and Woodford, 2003) where increasing the inflation target *would* have an effect since the liquidity trap must abate and the economy can always achieve the higher inflation target in the future.

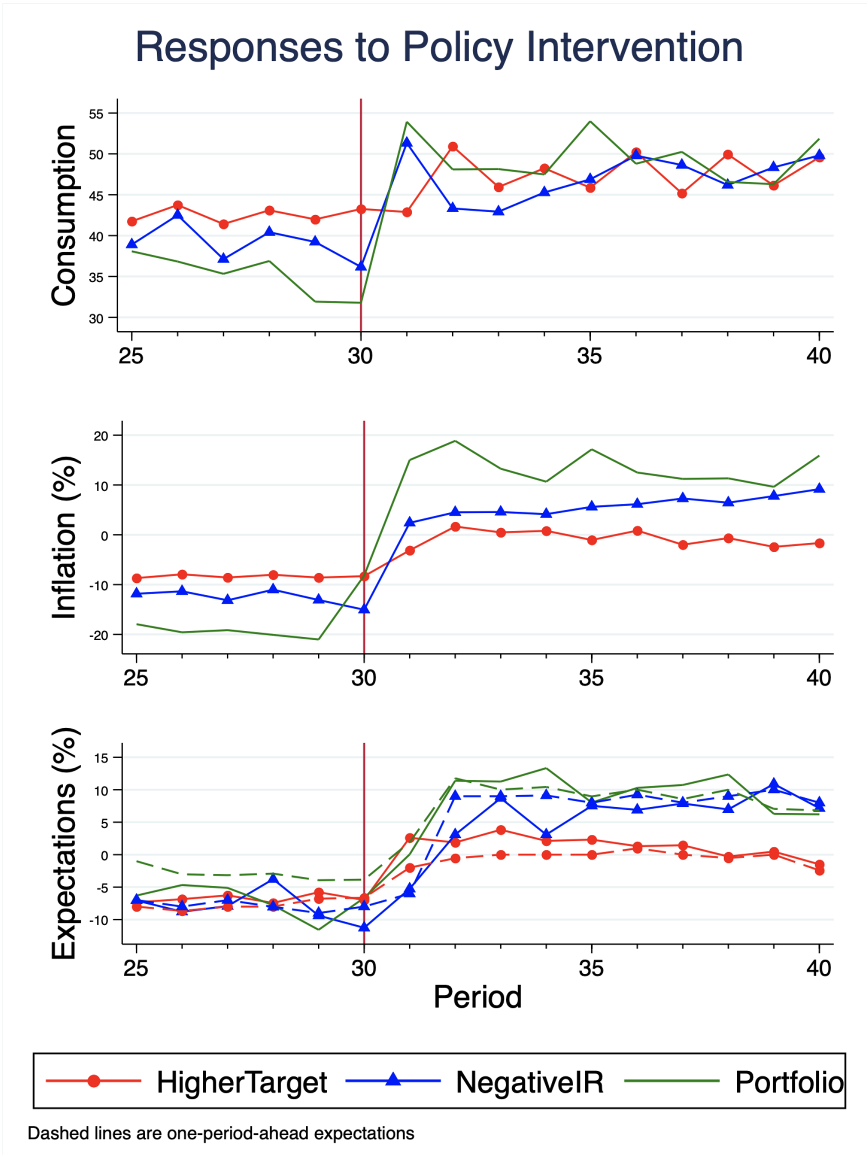


Figure 15: Aggregate dynamics around the policy intervention

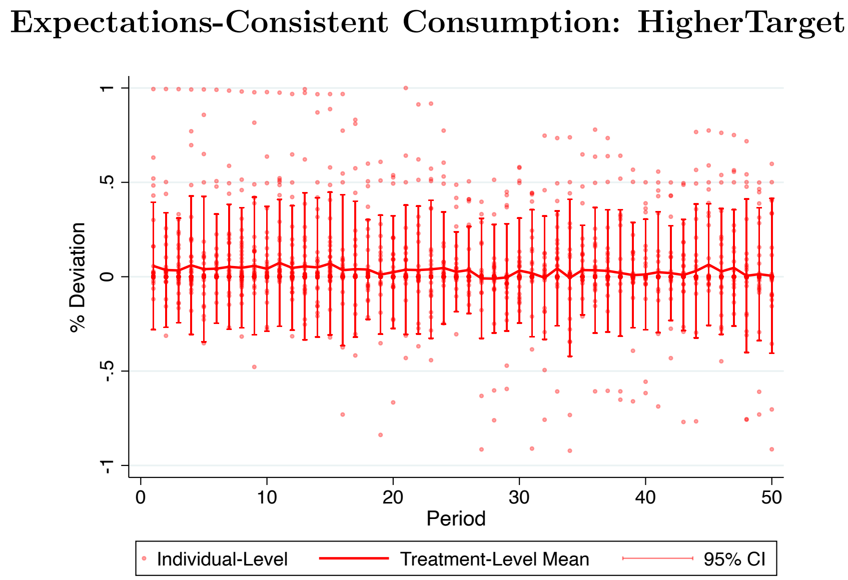


Figure 16: This figure shows deviations from expectations-consistent consumption in *HigherTarget*. Translucent dots are individual deviations, the thick line shows the treatment-level mean deviation, and the vertical spiked bars provide the 95% confidence interval around the treatment-level mean. The region above zero – relative to expectations-consistent consumption – denotes under spending and below zero denotes over spending.

Phase 1, and constant gains learning in Phases 2 and 3. This means that subjects base their expectations largely on the recessionary conditions at the end of Phase 2 – rather than on the new inflation target – when transitioning into Phase 3.

To summarize, increasing the inflation target in *HigherTarget* fails because the new target cannot coordinate subjects' backward-looking expectations. Instead, inflation expectations fall far short of the new target. Because consumption is expectations-consistent, this yields a significantly muted consumption response. The confluence of these two factors causes inflation to fall far-below target, an output gap, and depressed wages.

Why don't we see transition dynamics that lead us toward the full-employment equilibrium? The initial under-reaction to the increased inflation target does very little to assuage the concerns of any subject who initially perceived the intervention as non-credible. The under-whelming effect on impact of the intervention further reduces the perceived credibility of the new inflation target with all subjects. This is evident in the gradual decline of expectations over the subsequent periods of Phase 3 (red lines in the expectations panel of Figure 15).

Next we consider *NegativeIR* and *NegativeIR+Portfolio*. For negative nominal rates to be effective, we would expect agents to dynamically optimize in response to negative interest rates. Anticipating the possibility of negative interest rates, agents should respond by increasing their spending. Increased spending and expected spending should lead to increased nowcasts and forecasts, and in turn even greater spending. Together, these forces should lead economies to converge to the full-employment equilibrium.

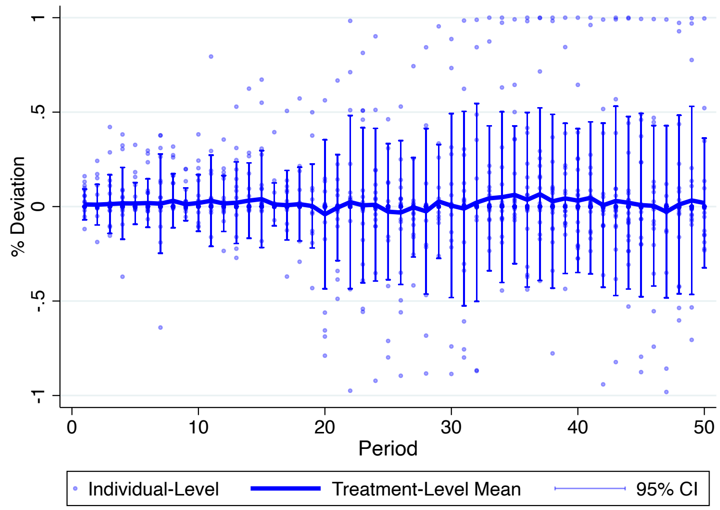
As was true with subjects in *HigherTarget*, subjects in *NegativeIR* and *NegativeIR+Portfolio* do make real decisions that are consistent with their inflation expectations (see Figure 17). Also clear from this figure is that subjects' consumption decision respond in a way that is qualitatively consistent with prevailing rates in our negative rates treatments. In both *NegativeIR* and *NegativeIR-Portfolio*, consumer spending increases by an average of more than 80% on impact of the interventions.

Do inflation expectations respond to the introduction of negative interest rates? Yes. this is visible in the expectations panel of Figure 15, where both treatment-level nowcasts and forecasts increase in the period immediately following the announcement of the new policy change. Because subjects have gained no new economic information, this response in expectations must be driven by the announcement of the new policy, their own spending decisions, or both.

Table 3 presents Granger causality tests for using session-level aggregate results within a 5-periods before and 5-periods after the intervention and evaluate the direction of causality in consumption and expectations. Consistent with our story, we see that the increased consumption following the policy intervention Granger causes inflation expectations in subsequent periods in the negative rates treatments. This effect is statistically significant at the 1% level. The opposite is true for *HigherTarget*, which further bolsters the idea that intervention in *HigherTarget* fails precisely because expectations under-react to the new target because participants do not perceive it as credible.

Why are negative rates still effective in *NegativeIR+Portfolio* where at least some subjects choose to hold cash? This is because enough subjects continue holding bonds that aggregate dynamics shift in a theory-consistent way in response to the introduction of negative rates. This means we see inflation, higher inflation expectations, higher wages and higher output following intervention. Because of this, subjects holding cash in later periods face similar erosive effects on their real wealth due to experiencing inflation without the counter-balancing effect of positive interest rates. Though this effect is not as strong as that experienced by subjects holding bonds, it does reinforce the expansionary effects of negative rates.

Expectations-Consistent Consumption: NegativeIR NegativeIR+Portfolio



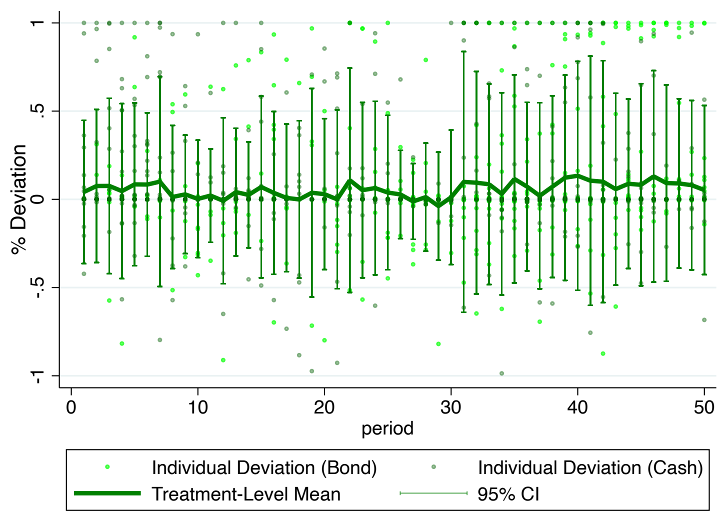


Figure 17: This figure shows deviations from expectations-consistent consumption in *NegativeIR* and *NegativeIR+Portfolio*. Translucent dots are individual deviations, the thick line shows the treatment-level mean deviation, and the vertical spiked bars provide the 95% confidence interval around the treatment-level mean. The region above zero – relative to expectations-consistent consumption – denotes under spending and below zero denotes over spending.

Treatment	$\mathbf{C} \rightarrow \mathbb{E}_t\pi_{t+1}$	$\mathbb{E}_t\pi_{t+1} \rightarrow \mathbf{C}$
HigherTarget	-	***
NegativeIR	***	-
NegativeIR-Portfolio	***	-

Table 3: This table reports the results of Granger causality tests. We use session-level data to test for each treatment whether consumption Granger causes inflation expectations or inflation expectations Granger cause consumption. We restrict our sample to a 10-period window around the policy intervention. *** denotes significance at less than a 1-percent level and - denotes no significance.

8 Conclusion

This paper introduces a novel experimental framework meant to test-bed unconventional monetary policies. We use the framework to explore the ability of two prominent unconventional policy alternatives to address recessions driven by secular changes. We build our framework around a simple 3-period OLG model of secular stagnation in a closed economy introduced in Eggertsson, Mehrotra, Robbins (2019). Subjects in our experiment form nowcasts and forecasts of inflation, and solve a repeated two-period optimization problem. Our experimental economies evolve endogenously according to these decisions. We introduce a permanent deleveraging shock into these economies, which depressed spending of automated young households. This places downward pressure on inflation and creates a unique secular stagnation equilibrium.

We test the ability of two prominent unconventional policy alternatives to address potentially permanent output gaps that arise in response. Increasing the central bank's inflation target creates a multiplicity of equilibria. Our interest is in equilibrium selection. Alternatively, allowing the central bank to use negative nominal rates restores the unique full-employment equilibrium.

Equilibria predicted by this model often obtain even though subjects form expectations using backward-looking heuristics that are much less sophisticated than rational expectations and least-squares learning (as explored by Gibbs (2017)). Unique, inflationary equilibria are relatively robust to deviations from optimal consumption. However, systematic over-consumption driven by Pigouvian wealth effects, coupled with sluggish adjustment of expectations, can prevents many experimental economies from converging to the secular stagnation equilibrium. Nevertheless, deleveraging shocks consistently create secular stagnation in many of our experimental economies and deflationary traps of various magnitude in the remaining economies. Thus, almost all experimental economies warrant intervention to stave off recessionary forces induced by secular forces.

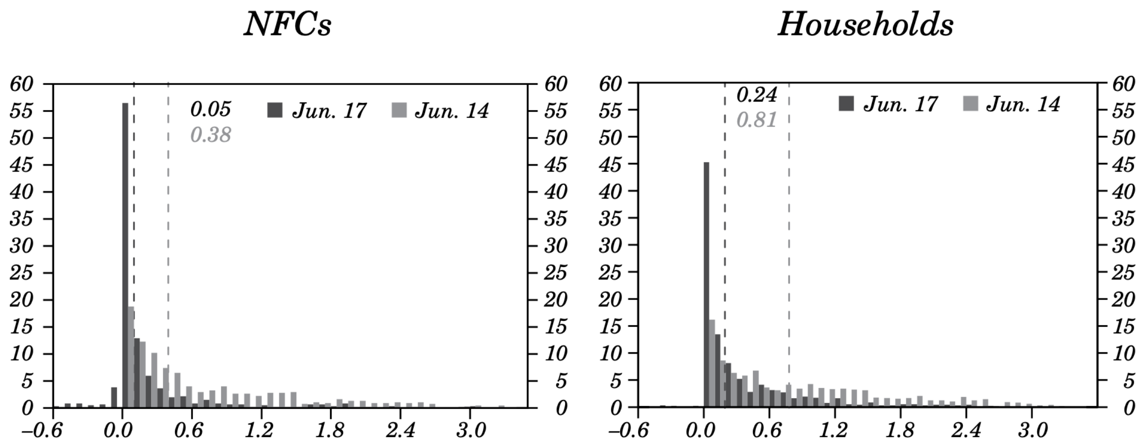
Increasing the central bank's inflation target consistently fails to pull economies out of deflationary traps. This result is consistent with Arifovic and Petersen (2017) who find that neither qualitative nor quantitative communication of higher inflation targets in a liquidity trap is sufficient to stimulate inflation expectations in a learning-to-forecast experimental environment. This intervention hinges critically on its ability to coordinate the expectations of forward-looking, dynamically optimizing agents on the higher target. However, subjects in our experiment overwhelmingly employ backward-looking forecast heuristics, which mutes the effect of this intervention on impact. An underwhelming response to the policy intervention further erodes the new target's already-tenuous credibility, which leads to a slow decline in inflation expectations, inflation, output, and wages.

Implementing negative interest rates consistently causes our experimental economies to converge to the unique full-employment equilibrium. This is because dynamically-optimizing subjects in our experimental economies fully internalize the effects of anticipated negative interest rates. That is, subjects immediately increase spending upon impact and account for this increased spending in their inflation nowcast. Further, subjects anticipate that negative rates will persist and incorporate this into their inflation forecasts.

Introducing a portfolio choice does not significantly erode the ability of negative interest rates to stimulating aggregate demand and inflationary expectations. Rather than hoard cash, a majority of subjects in our experimental economies continued to hold bonds and incorporated negative rates into their real decisions. This led to rapid adjustments of inflation and inflationary expectations, which worked in tandem to pull our experimental economies out of deep deflationary traps.

Results from our *NegativeIR* and *Portfolio* suggest that real-world implementations of negative interest rate frameworks were perhaps unnecessarily handicapped by the refusal of commercial banks to impose negative deposit rates on households (See Figure 18). This refusal closed the the important transmission channel of intertemporal choice. Perhaps surprisingly, our results suggest that households are willing to endure some degree of negative interest rates and that aggregate demand would respond to these negative rates.

This suggests a more subtle cost imposed by commercial banks who were unwilling to pass negative rates thru to households: It is possible that negative rates implemented in the Euro area persisted longer than necessary given their potentially muted effect. If instead commercial banks had passed negative rates thru to deposit rates, we might have seen a sharp demand response leading to inflationary pressure and more optimistic inflation expec-



Source: ECB.
Dashed lines represent mean of distribution.

Figure 18: This figure, taken from Eisenschmidt and Smets (2019), shows the distribution of rates charged by commercial banks on deposits held by households and NFCs following the implementation of negative interest rates by the ECB in 2014 and 2017. Pass thru of negative rates to financial markets was complete. However, commercial banks imposed a zero lower bound on households out of fear that pass thru would lead households to withdraw deposits and instead hold savings as cash.

tations. Together, these forces could have created sufficient inflation to generate space for conventional policy.

Our results also suggest that we should possibly rethink how we interpret existing evidence on the efficacy of negative rates, since a negative rates framework not plagued by this lack of pass thru to deposit rates would likely be more effective more quickly than the partial frameworks we've seen implemented in the past.

Another important benefit of this framework is that it produces individually-linked expectations and consumption data. This rich data source allows important insight about the relationship between expectations and real decisions that compliment an existing empirical literature (Examples are D'Acunto, Hwang, Webber (2016); Coibion et al. (2019); Coibion et al. (2020)). For example, a critical ingredient of understanding why increasing the inflation target fails in our framework is discerning between decisions inconsistent with expectations or and under-reaction of expectations to the new target. Further, our results generally support the notion that inflation expectations are an important component of real-world consumption and savings decisions.

Over all, our results lead to clear policy implications for stimulating aggregate demand in response to recessionary pressure generated by secular forces. Namely, policies that impact real wealth balances are more effective than those driven thru the expectations channel.

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9 Appendix

9.1 Session-Level Data with Individual Consumption and Expectations

9.1.1 *Baseline*

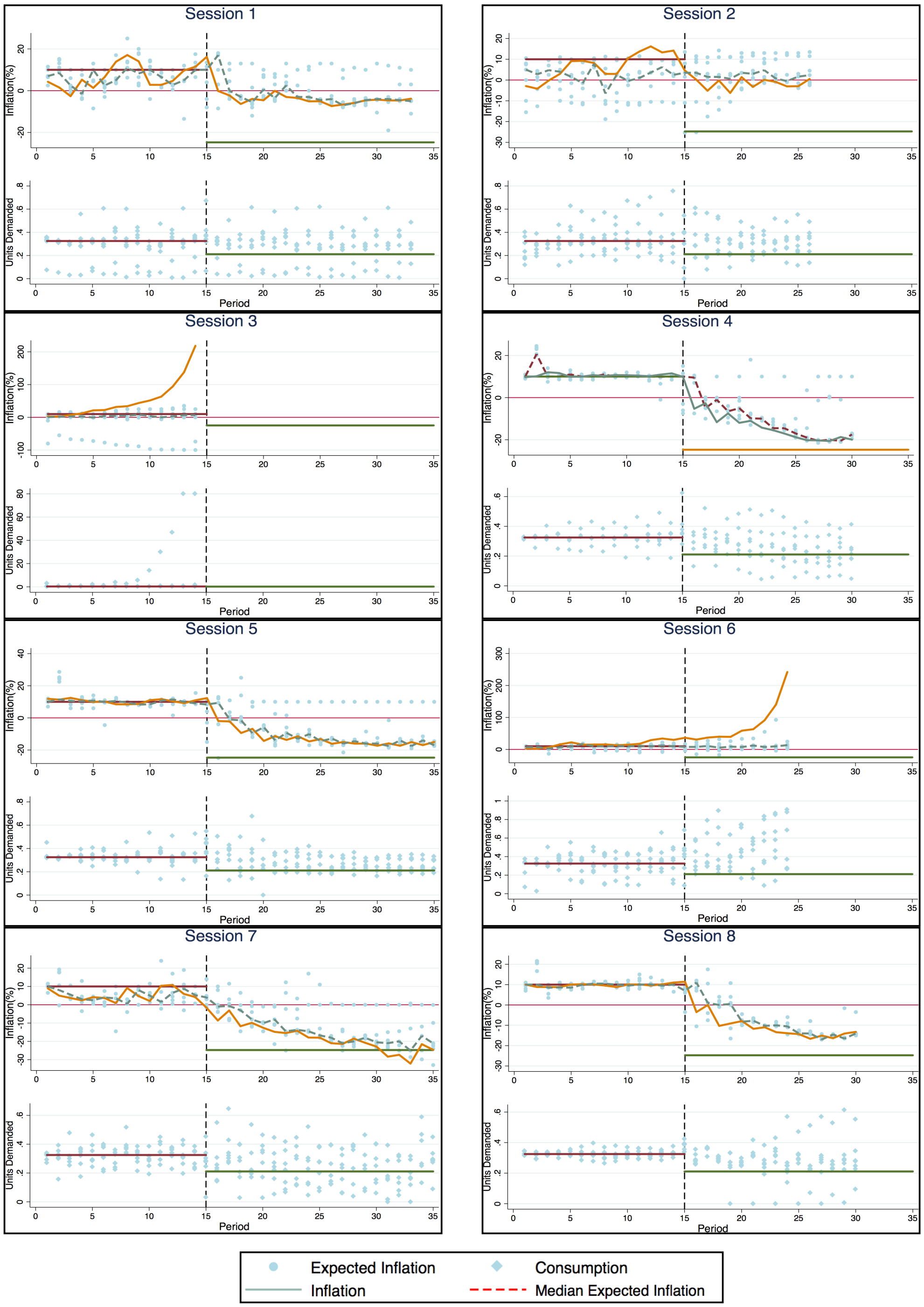

Figure 19: Aggregate inflation by session for *Baseline*

9.1.2 *HigherTarget*

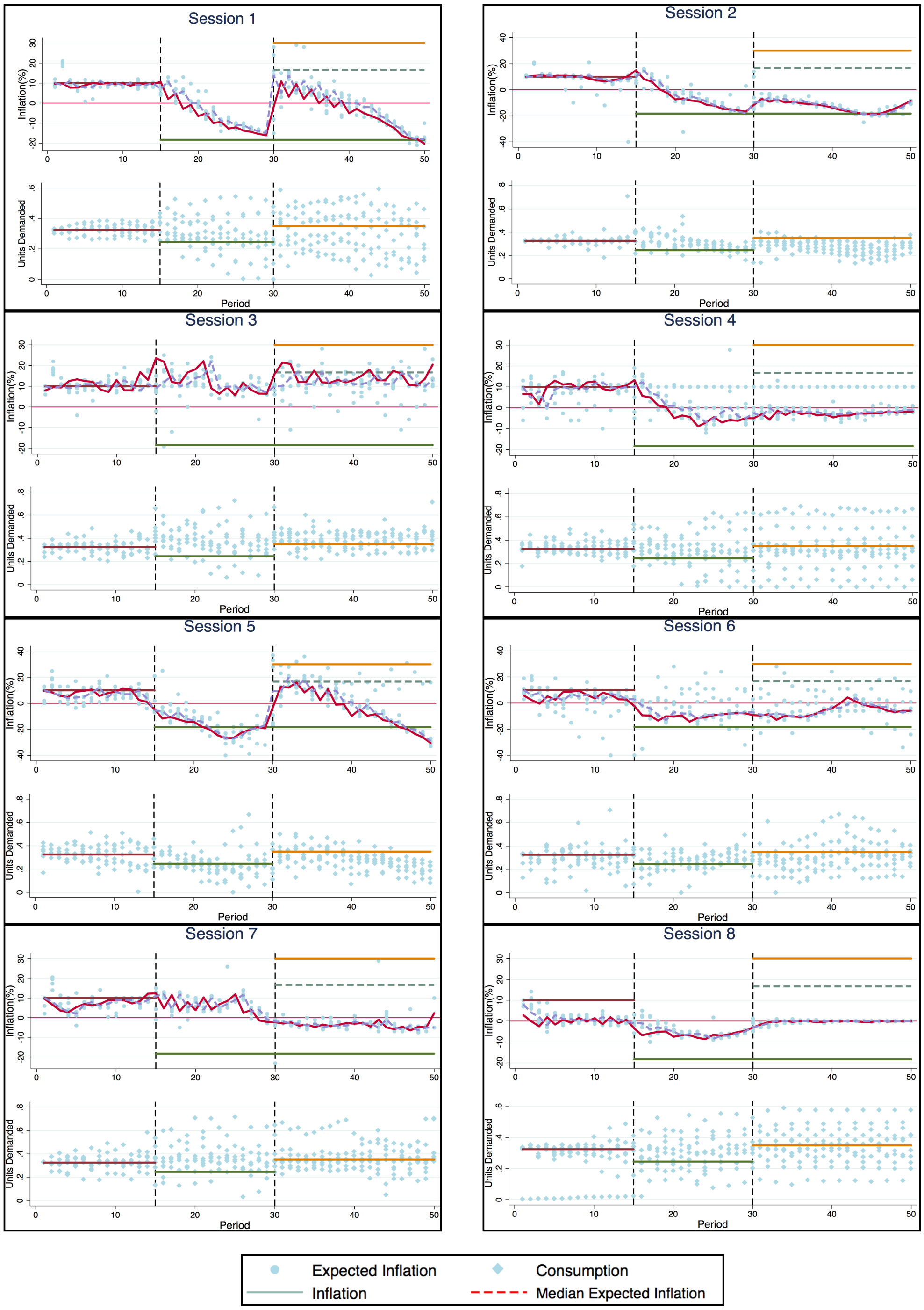

Figure 20: Aggregate inflation dynamics by session for *NegativeIR*

9.2 NegativeIR

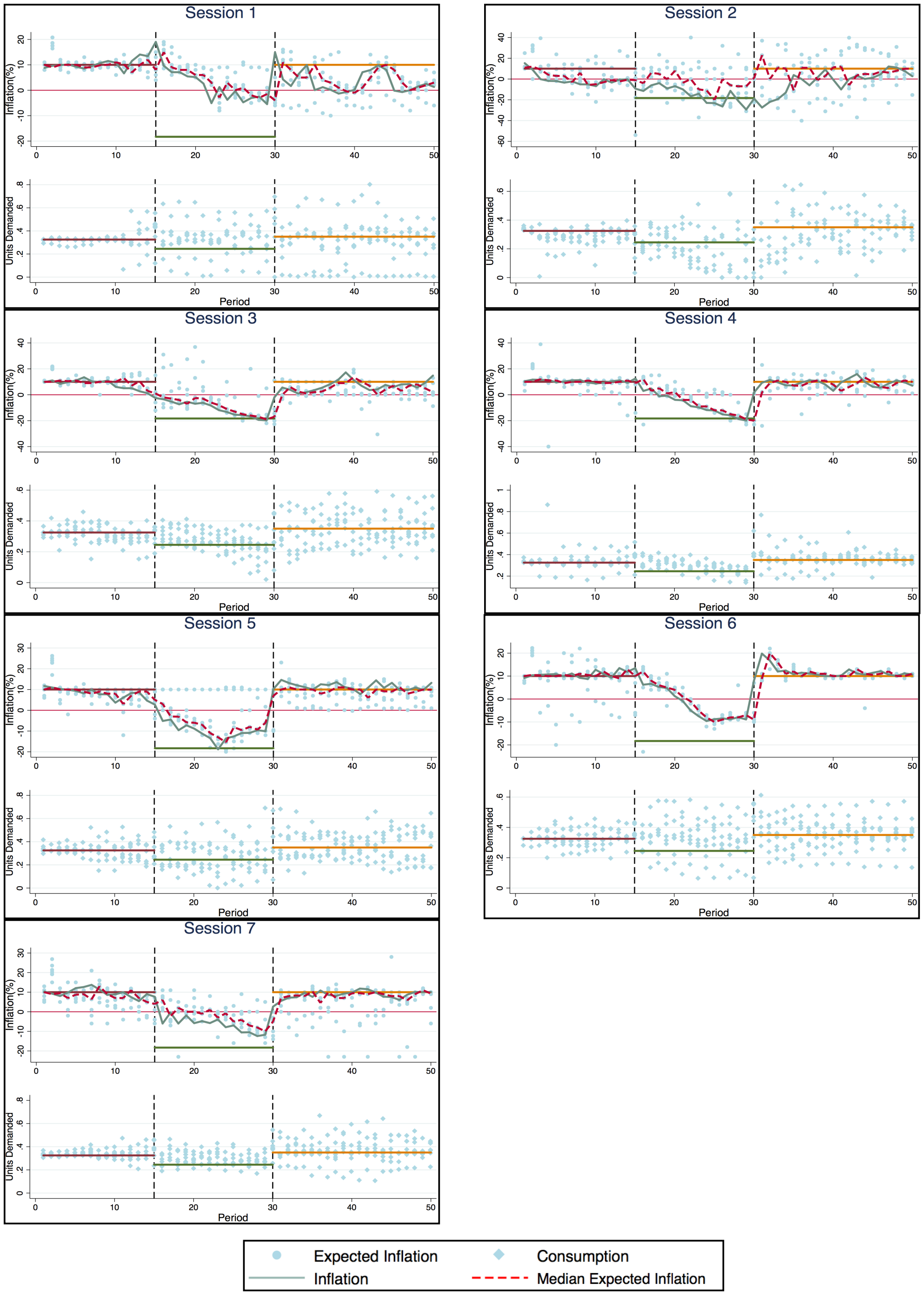

Figure 21: Aggregate inflation dynamics by session for *NegativeIR*

9.3 NegativeIR+Portfolio

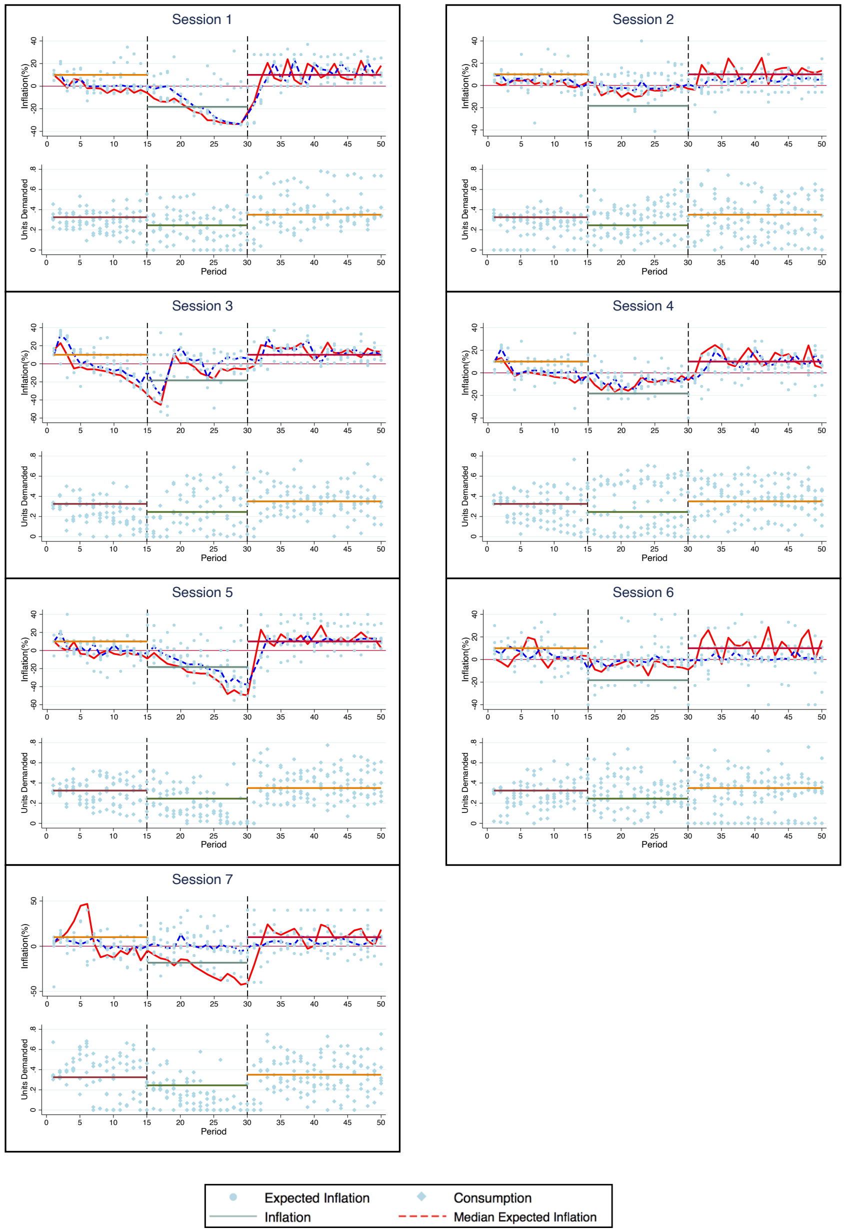

Figure 22: Individual-level dynamics from NegativeIR+Portfolio