Escaping secular stagnation with unconventional monetary policy*

Luba Petersen **Ryan Rholes**

Simon Fraser University Texas A&M University

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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 that precipitate persistently deflationary episodes. These shocks generate considerable consumption heterogeneity and also change subjects' forecasting heuristics to make them more backward-looking. We experimentally test policies aimed at re-anchoring expectations and the economy on the high inflation steady state. Permanently increasing the central bank's inflation target is insufficient to generate inflationary expectations. Eliminating the zero lower bound, on the other hand, 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, communi-

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cation, credibility, laboratory experiment, experimental macroeconomics

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. Furthermore, these conditions persist 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 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 described this proximity to the effective lower bound as "the pre-eminent monetary policy challenge of our time" as central bankers sought out fresh policy tools.

Now, the unprecedented economic crisis brought on by the global pandemic has highlighted the pressing need to expand the tool kits of policy-makers. 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 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 and a secular stagnation of the economy.

In our *Baseline* treatment, We find that most economies converge toward the initial full-employment equilibrium and that deleveraging shocks consistently generate pessimistic expectations and typically manufacture various degrees of instability manifesting itself either in permanent deflation. In most sessions the economies converge in the direction of the secular stagnation equilibrium.

We then explore alternative policy options to return the economy to its full employment equilibrium after an extended episode at the zero lower bound. In our *HigherTarget* treatment, we raise the inflation target from 10-30%, one policy prescription formalized by EMR. We find that significantly increasing the central bank's target, which in theory yields a multiplicity of equilibria, does not effectively return any of the economies to the targeted, full-employment equilibrium. On the other hand, removing the ZLB in our *NegativeIR* treatment consistently stimulates spending, which in turn encourages inflationary expectations and a quick escape from the zero lower bound. These economies stabilize at a 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 is 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 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 economics literatures. Section 3 lays out the theoretical framework and hypotheses for our experiment. Section 4 providedis 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.

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

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

inflation targets constant or reduce 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 an extreme lack of 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. XYX use Euro Area data to show that negative policy rates increase the growth rate of banking credit through a re-balancing of bank portfolios from liquid assets to credit supply.

Our experiment contributes to this literature by building a flexible framework capable of producing empirical data surrounding the use of higher inflation targets and negative policy rates. Our results mostly align with this existing literature in the sense that negative rates in our experimental economies stimulate aggregate demand yielding an expansionary effect. Importantly, our framework provides insight to how individual decisions and expectations respond to negative policy rates, thereby shedding light on a transmission channel of negative rates that real-world data alone cannot elucidate.

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 methodolgical contributions to this literature. First, we introducing a novel approach to modeling OLG economies in the laboratory **(discussed in detail in the design section).** 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 policy-relevant questions in production economy settings. 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_t^y, B_t^m 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

$$\frac{1}{C_t^m} = \beta \mathbb{E}_t \frac{1}{C_{t+1}^o}(1+i_t)\frac{P_t}{P_{t+1}} \tag{7}$$

3.2 Firms

Firms are perfectly competitive price takers with technology $Y_t = L_t^\alpha$ 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.

To understand the impact of a deleveraging shock, suppose an inflationary economy faces

[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.

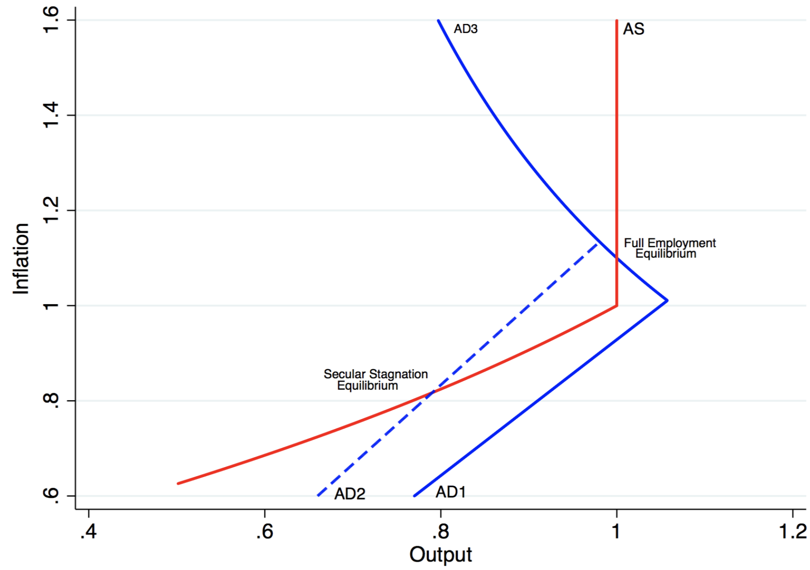

Figure 1: A deleveraging shock moves an economy from a unique inflationary to a unique secular stagnation equilibrium.

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:

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

[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.

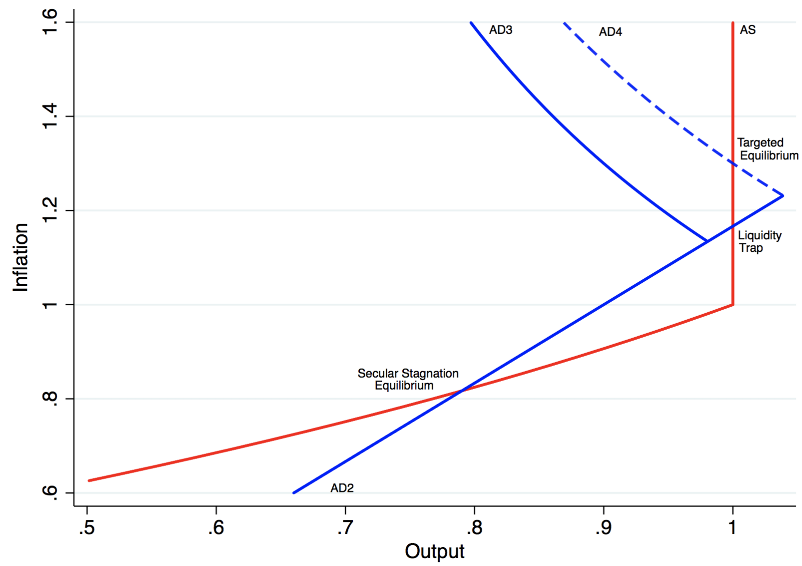

Figure 2: Increasing the inflation target generates two inflationary equilibria: a target, full-employment equilibrium and a liquidity trap equilibrium.

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.[7]

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

[7] The increase in inflation target from 10 to 30% is certainly extreme, but is necessary given our parameterization that allows for more linearity in the households' utility function. Nonetheless, in thinking about future policy actions at the 2019 Jackson Hole Symposium, former Federal Reserve governor Randall Kroszner said 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".

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 intended inflationary 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

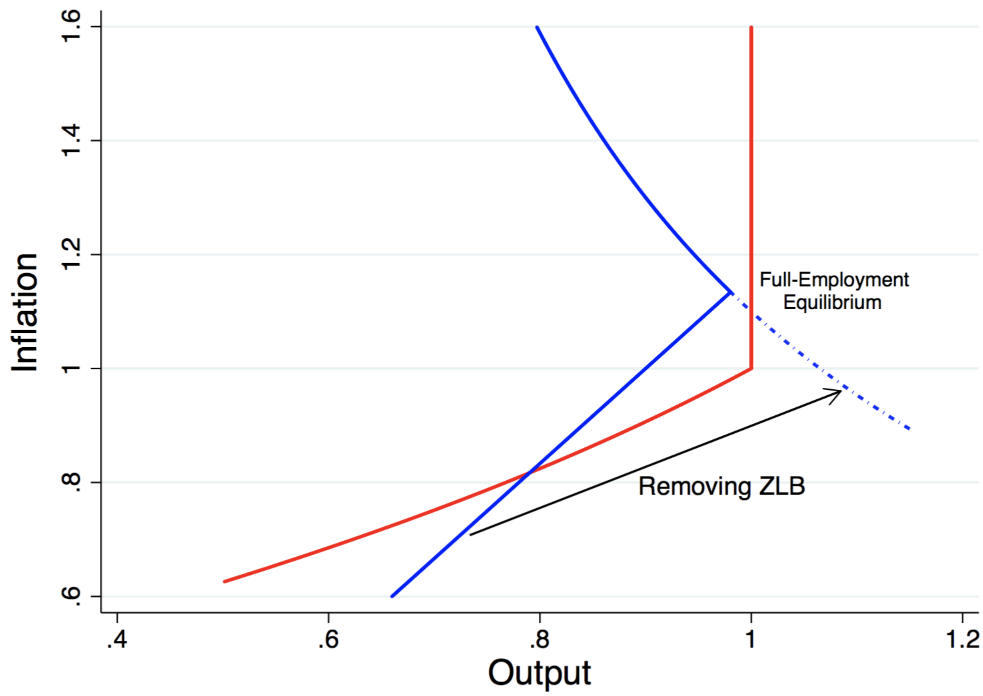

Figure 3: Removing the ZLB removes the kink from the AD curve, thereby eliminating the secular stagnation equilibrium and creating instead a unique inflationary equilibrium.

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.[8] 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:

[8] 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.

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

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.[9] 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.

[9]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.

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

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 $\alpha = 0.00673$.[10] Since a participant is essentially two households at any 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

[10] 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 $C_t = 0$.

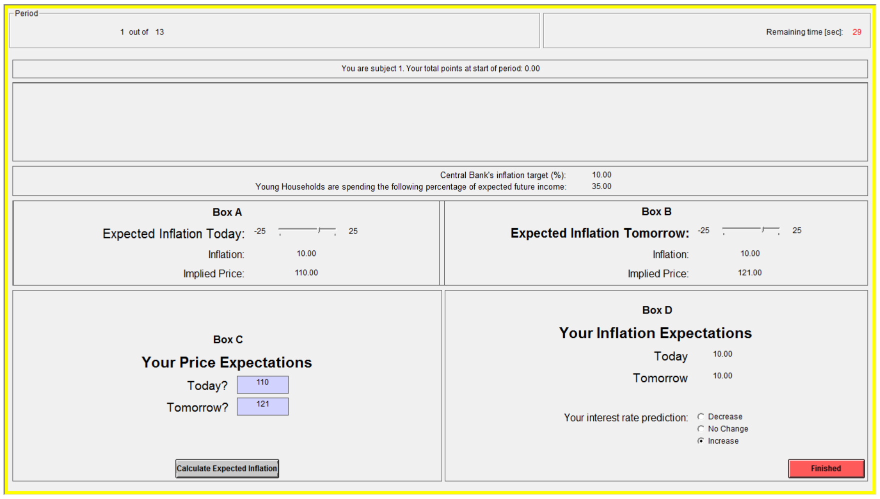

Figure 6: Stage 1 Screen

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 experimental 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 as-

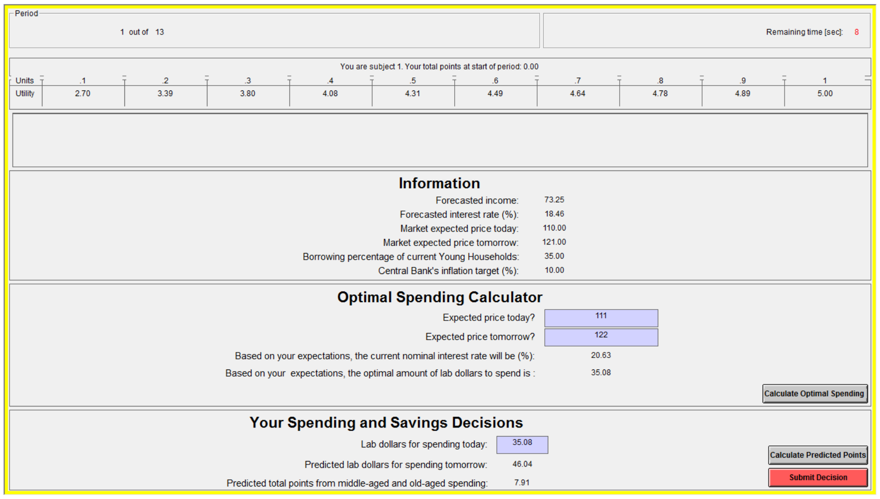

Figure 7: Stage 2 Screen

suage 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.

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,

$$i. \quad b = \frac{1-\alpha}{\alpha}$$

$$ii. \quad A = C(1-\gamma)\alpha \overline{L}^{\alpha-1}$$

$$iii. \quad B = C\gamma w_{t-1}$$

,

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 housyoungehold 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 finally 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.[11] 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.[12]

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 $D^{shock} = .3$ [13] 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 and allowing a negative nominal interest rate. Raising the inflation target generates multiple equilibria: a

[11] 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.

[12] 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.

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

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 with the central bank's inflation target.

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.

We summarize the treatment parameterization 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	$\pi^{tgt} = 10\%$	$\pi^{ss} = -18.3\%$	$\pi^{tgt} = 10\%$

Table 1: Parameterized equilibria across treatments and phases

5 Results

We begin with results from *Baseline*, where we initialize our experimental economies with a unique inflationary equilibrium and then replace this with unique secular stagnation equilibrium via a sharp deleveraging shock. Results for this treatment are shown in Figure 8. This figure plots individual inflation expectations, the median inflation expectation, aggregate inflation (top panel), and individual consumption demand (bottom panel) from each *Baseline* session. Note that each session-level graph is split into two phases: a pre-shock phase and a post-shock phase. The vertical, dashed line denotes the period of the deleveraging shock and the two horizontal lines denote the pre-shock, full-employment and the post-shock, secular stagnation equilibrium levels of inflation (top panel) and consumption (bottom panel).

In four of the eight sessions, the economies appear to be converging to the steady state equilibrium in the pre-shock phase of each session. This is particularly impressive given that, as we discuss later in the results section, the overwhelming majority of subjects abstain from simply forecasting the central bank's inflation target in each period and instead adapt a forecasting heuristic that involves updating as a function of recent economic outcomes. The deleveraging shock, which occurs in period 15, consistently generates deflation. However, not all economies completely converge to the secular stagnation equilibrium following this shock. Instead, we see varying degrees of deflation emerge ranging from mild deflation to severe deflation at the secular stagnation equilibrium. The inability of economies to completely converge to the secular stagnation is most often attributable to over-consumption that emerges once subjects begin to experience deflation (see Figure 10). That is, we find evidence of a Pigou effect (Patinkin, 1948), whereby deflationary episodes are quelled by a wealth effect generated by increasing real wealth balances.

The economies in sessions 3 and 6, however, experience rampant inflation. This is driven by a confluence of highly optimistic expectations and very large spending shocks. This is striking given that the central bank pursues an aggressive policy response to inflation and is unrestrained in adjusting its policy rate upwards. In fact, as expectations remain anchored despite increasing rates, we eventually see that pursuing a Taylor-type rule reinforces rather than dampens this inflationary pressure. The lack of responsiveness of the economy to the high interest rate suggests that the wealth effect strongly dominates the substitution effect for participants.

Worth noting in Figure 8 is how consumption changes in response to the deleveraging shock. Session 8 gives a nice example. Though consumption is relatively well anchored in phase 1 of each session, we see that the deleveraging shock and subsequent deflationary pressure drastically increases consumption heterogeneity, which suggests that such shocks reduce aggregate welfare but the decrease in welfare is larger for some than others. This pattern emerges in most of our experimental economies.

Figure 9 follows the same conventions as Figure 8 but plots the nominal interest rate rather than nominal inflation. We see here that the central bank is constrained by the zero lower bound almost immediately following a deleveraging shock. Nevertheless, this drastic reduction in interest rates does little to stimulate aggregate demand.

Additionally, we examine consumption demand aggregated across phases one and two of *Baseline*. We show this in Figure 10, which plots the cumulative density function (CDF) for aggregate demand of all participants across all periods for phases one and two of *Baseline*. The two vertical lines denote optimal consumption demand for an individual under rational expectations. The leftmost vertical line denotes optimal post-shock consumption while the rightmost line denotes optimal pre-shock consumption. The dashed density line is the post-shock CDF.

There are several things worth noting in Figure 10. First, we see that in Phase 1 of *Baseline*, our subjects, on average, consume approximately optimally relative to a fully rational economic agent. Further, we see that post-shock consumption is much higher than that predicted, which is the predominant reason that some economies do not converge fully to the secular stagnation equilibrium. This pattern of over consumption following a deleveraging shock emerges consistently across treatments.

HigherTarget embeds *Baseline* and explores aggressive inflation targeting as a method of

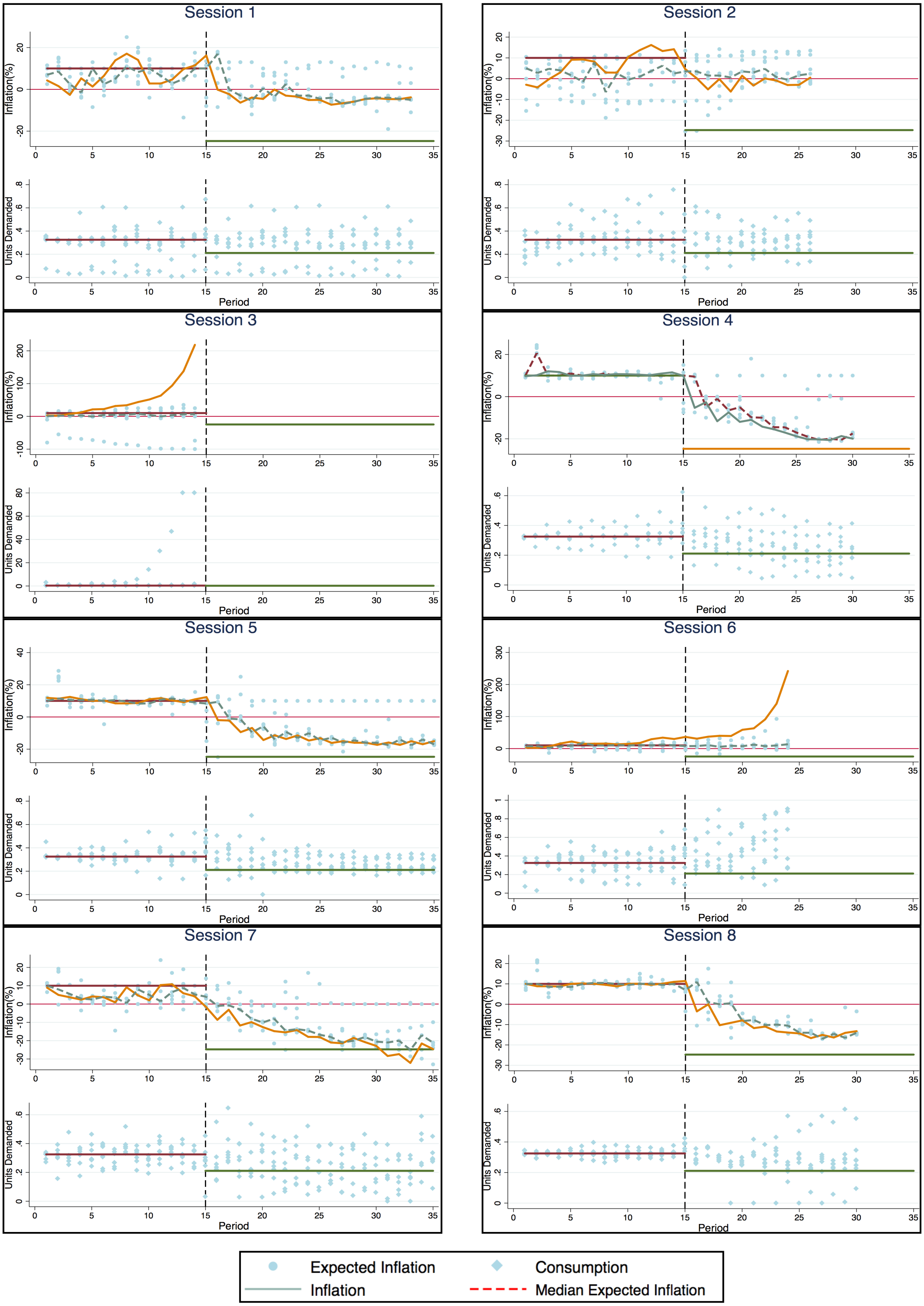

Figure 8: Aggregate inflation by session for *Baseline*

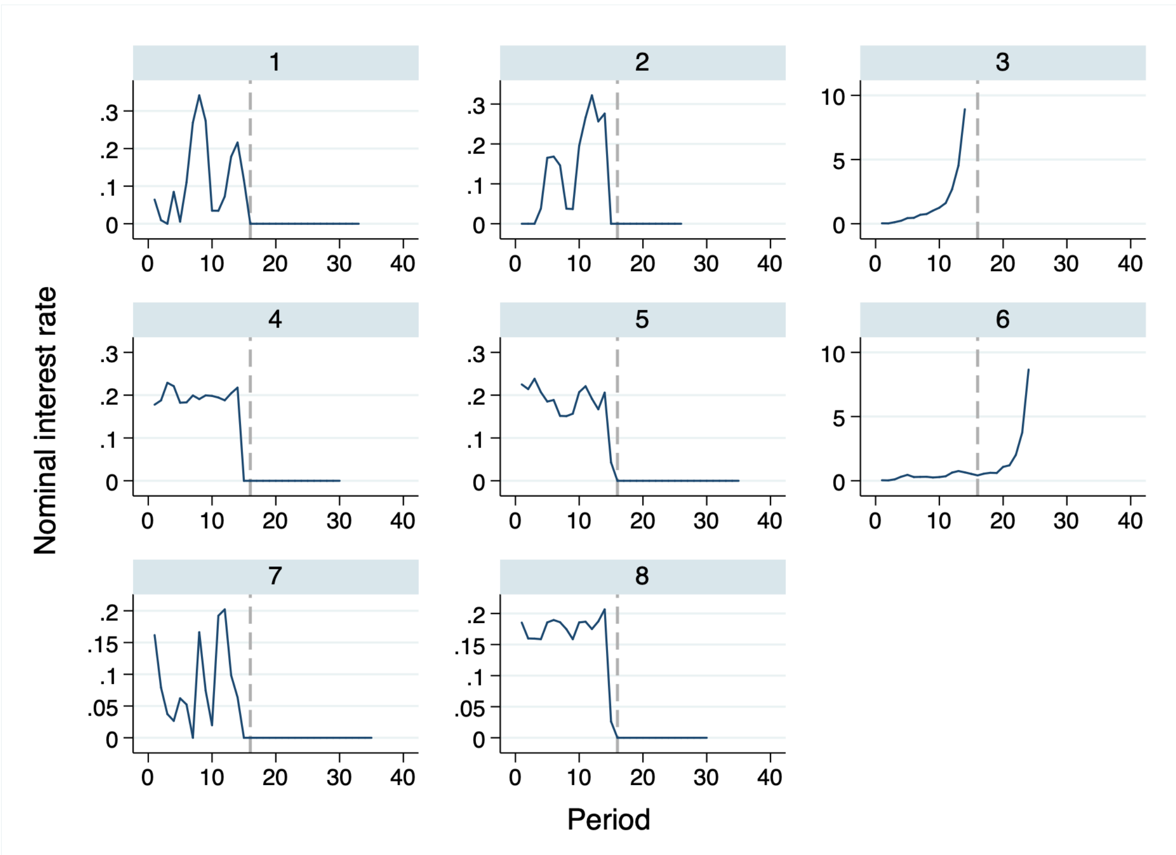

Figure 9: Nominal interest rates by session for *Baseline*

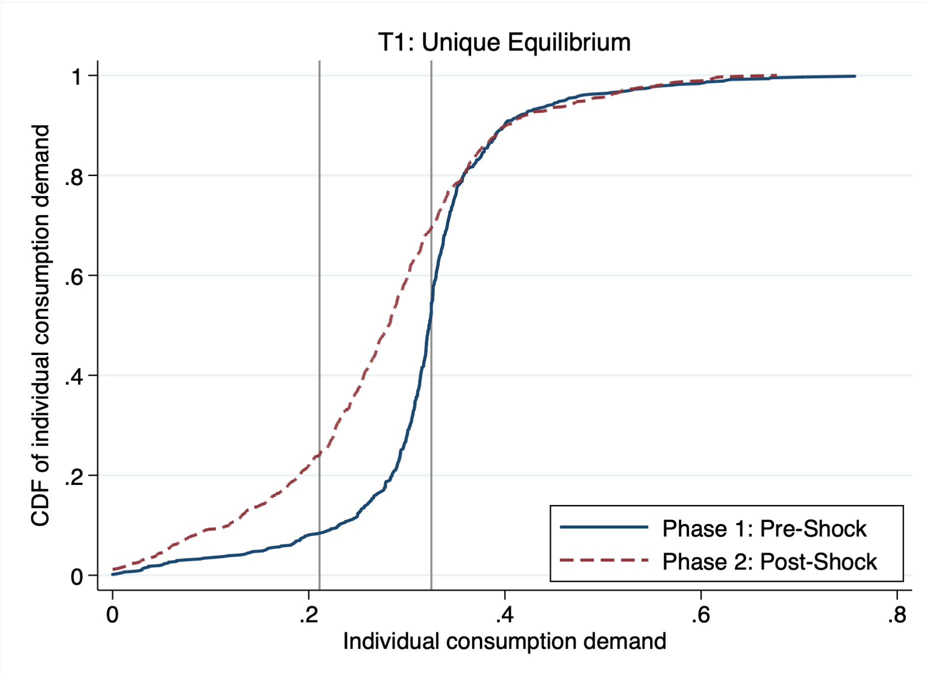

Figure 10: Nominal interest rates by session for *Baseline*

pulling an economy from secular stagnation. We show results from this treatment in Figure 11. We split *HigherTarget* session into three phases (from left to right): a pre-shock phase, a post-shock phase, and a post-intervention phase. Vertical dashed lines denote the timing of the deleveraging shock and the central bank's policy intervention, respectively. Horizontal lines denote equilibrium inflation and consumption levels. Note that phase 3 of *HigherTarget* features three horizontal lines. These correspond to the three equilibria depicted above in Figure 3. The top orange line is the full-employment equilibrium that coincides with the central bank's new inflation target, the grey dashed line (middle line in phase 3) denotes the liquidity trap equilibrium, and the solid bottom green line denotes the secular stagnation equilibrium.

Again, subjects in this setting do a good job of playing the inflationary equilibrium and we see that the deleveraging shock generates pessimistic expectations and deflationary pressure on the individual economies. Following deflationary episodes generated by the deleveraging shock, our mechanistic central bank attempts to address secular stagnation by increasing its inflation target. The idea here is that this new inflation target will generate optimistic, inflationary expectations that will fuel spending. This expectations-driven increase in demand in turn increases the borrowing and spending capacity of the Young and Middle-aged households through increased expected nominal income.

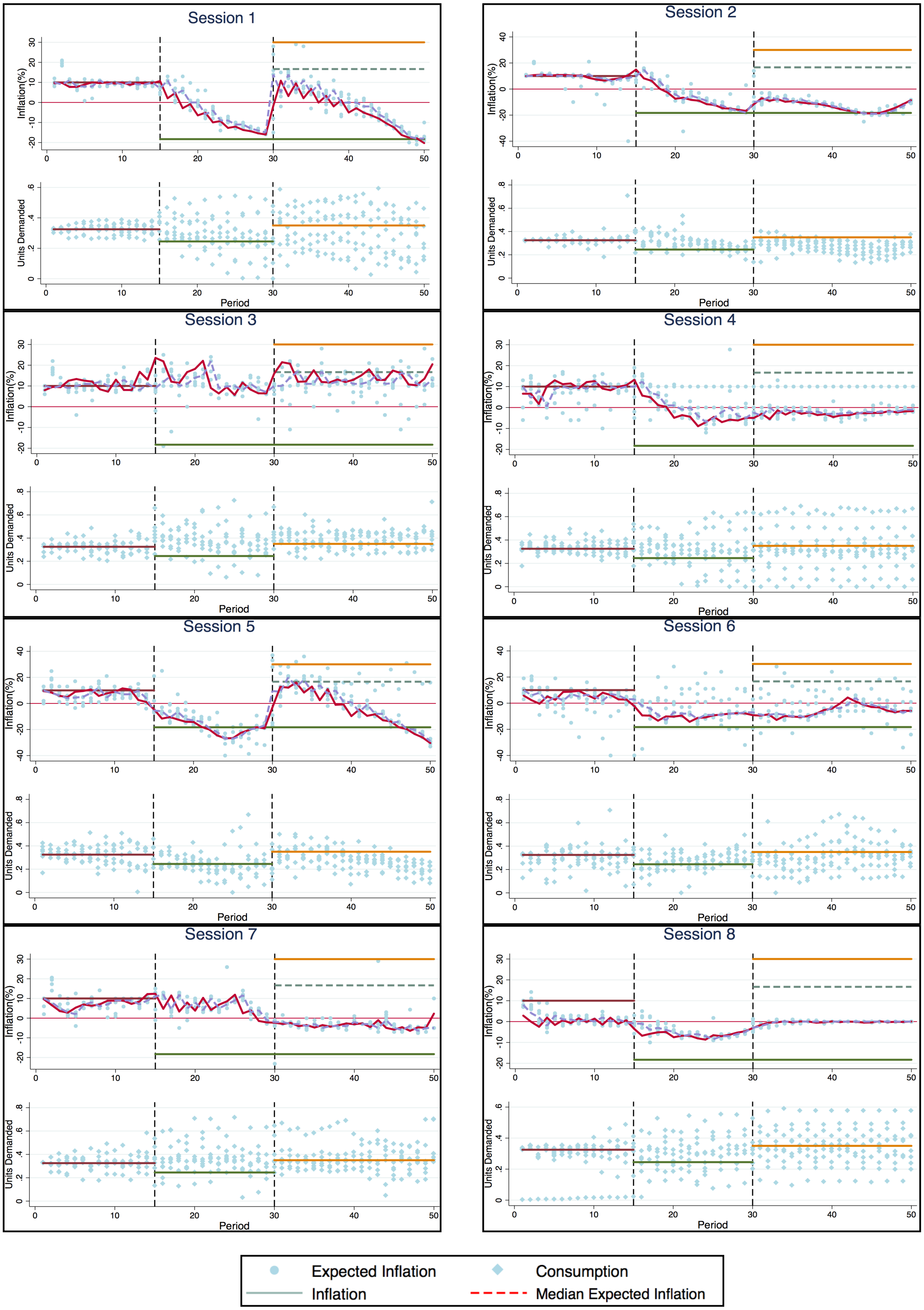

Figure 11: Aggregate inflation dynamics by session for *HigherTarget*

The increase in the inflation target ubiquitously fails to return the economies to the desired, full-employment equilibrium. Instead, we observe in most economies that inflation reacts very little to the increase in the inflation target. In economies where there is some initial reaction to the announcement/target increase (sessions 1, 2, and 5), there is a slow but steady collapse in inflation expectations and inflation, and a subsequent return to the secular stagnation equilibrium.

Also noteworthy is that some economies in the post-intervention environment do manage to mitigate deflation by coordinating on zero inflation. Interestingly, this model, in theory, does not feature a stable-price rational expectations equilibrium. However, we find that zero inflation often becomes a focal point for our economies. This tends to be the result of over-consumption that begins after subjects have experienced prolonged deflation. 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.

As was true in Figure 8, we see a considerable increase in consumption heterogeneity following the deleveraging shock. Worth noting here is that increasing the inflation target does little to coordinate inflation expectations on the central banks target and also has little coordinating effect on consumption.

We see in Figure 12 that nominal rates in this economy often exhibit quite a bit of volatility pre-shock, which yields relatively stable pre-shock inflation dynamics. And as was true in *Baseline*, we see that almost all of our economies converge almost immediately to the zero lower bound following our deleveraging shock. We see that from each of our economies[14], regardless of post-intervention dynamics, remains constrained at the zero lower bound post intervention.

We also consider consumption dynamics for *HigherTarget*, which we show in Figure 13. This graph is similar to the consumption graph from *Baseline*. However, we now display three density lines and three vertical lines depicting optimal consumption levels under rational expectations for each of the three phases of *HigherTarget*. The three vertical lines denote optimal levels (from left to right) for post-shock consumption, pre-shock consumption, and post-intervention consumption. The solid and dashed density lines depict the CDFs of phase 1 and phase 2 consumption, respectively. The dashed-and-dotted density curve depicts the CDF of post-intervention consumption.

As was true in *Baseline*, we see in Figure 13 that, on average, subjects consume optimally

[14] Aside from session 3.

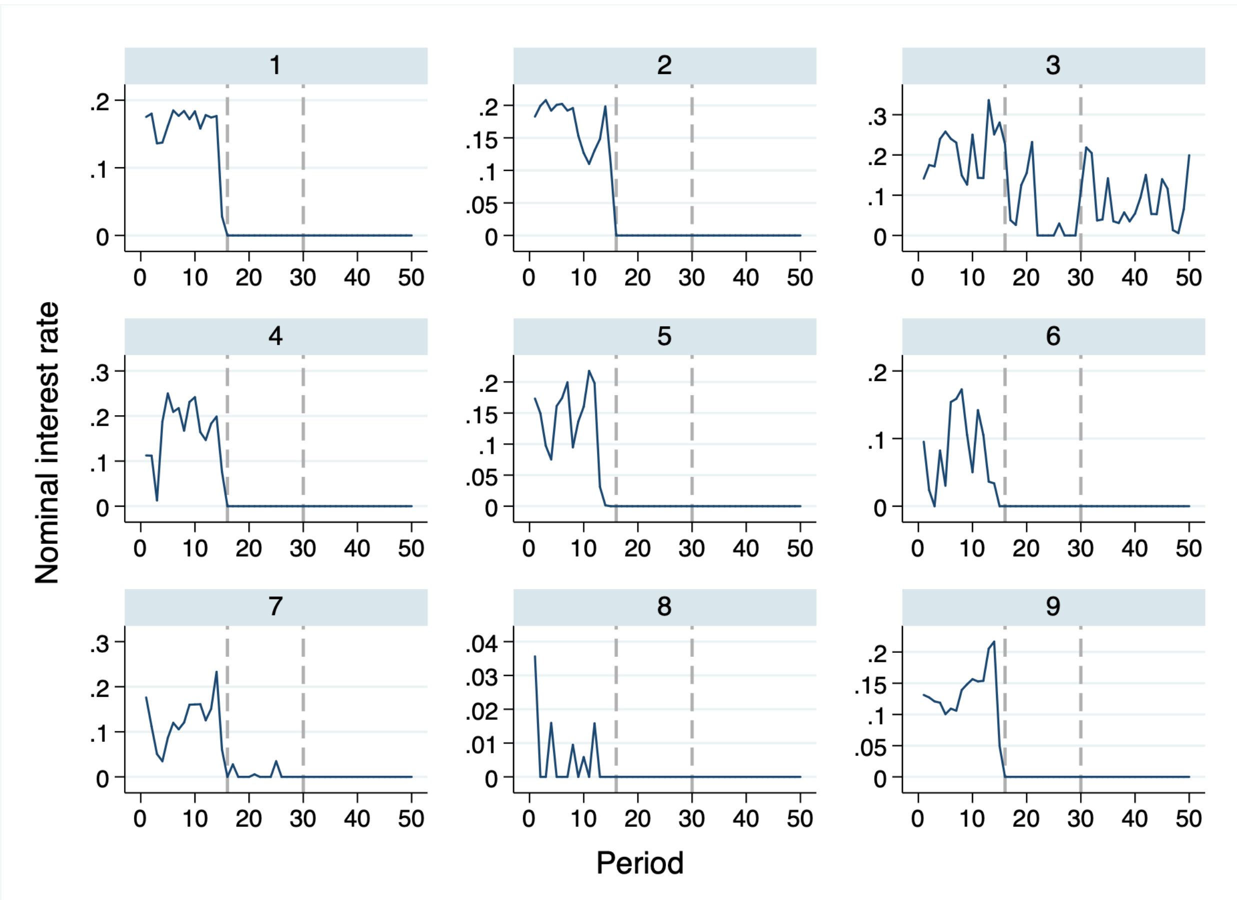

Figure 12: Nominal interest rates by session for *HigherTarget*

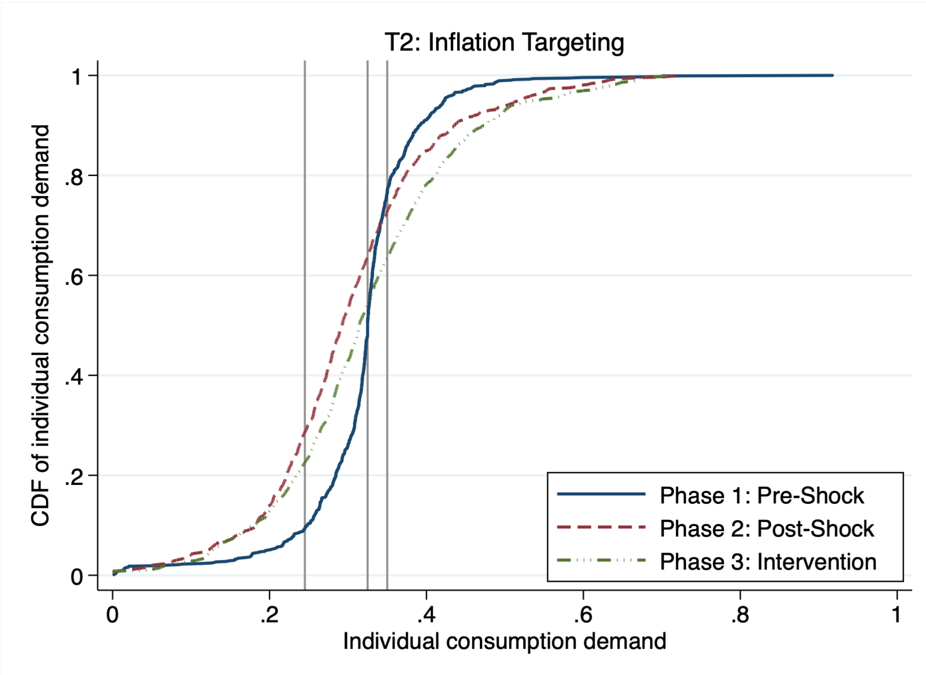

Figure 13: CDFs of consumption for all subjects in all periods of *HigherTarget*

in Phase 1 but over consume in Phase 2. We also see in Figure 13 that subjects under consume in Phase 3, which is driven at least in part by the inability of the central bank to re-anchor expectations on its higher inflation target. In additional to low demand of Middle-aged driven by pessimistic expectations, this sub-optimal demand is also driven by Young households borrowing against future income that is much lower than is theoretically predicted under rational expectations.

NegativeIR also embeds *Baseline*. However, the central bank in these experimental economies now intervenes by permanently removing the ZLB in an effort to stimulate inflation expectations and increase aggregate demand in the hopes of returning the stagnating economies to the full-employment equilibrium. Results from this treatment are shown in Figure 14.

As in *HigherTarget*, the central bank's policy intervention occurs at the beginning of period 30. There are two key differences between *NegativeIR* and *HigherTarget*. First, in *NegativeIR* there exists only a single inflationary equilibrium following the central bank's intervention. This equilibrium coincides with the central bank's inflation target of 10%. Second, the key mechanism pushing the experimental economies out of secular stagnation in *NegativeIR* is a negative nominal interest rate that stimulates aggregate demand by increasing the appeal of current consumption relative to future consumption. That is, there is relatively less reliance on rational expectations to stimulate spending.

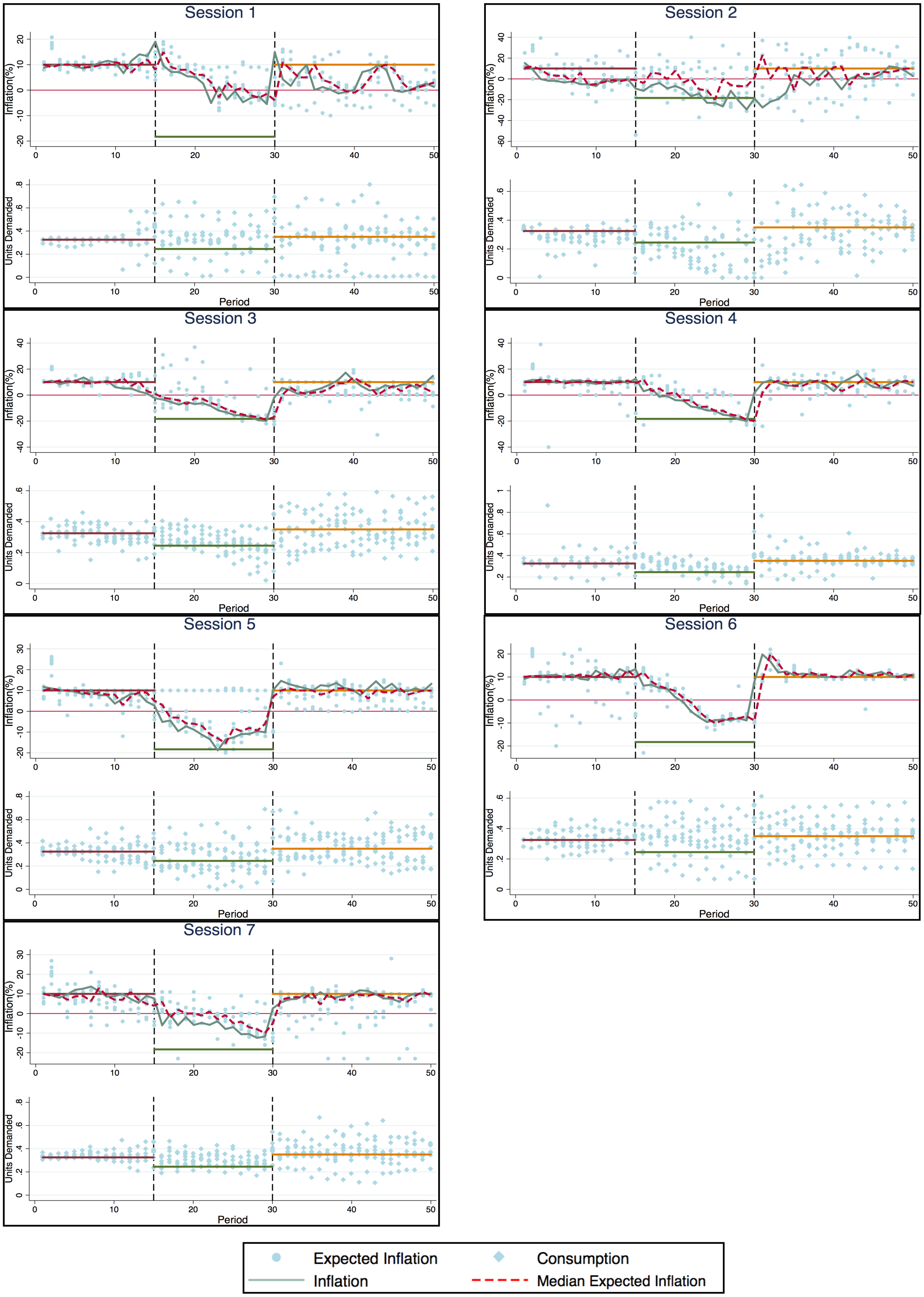

Figure 14: Aggregate inflation dynamics by session for *NegativeIR*

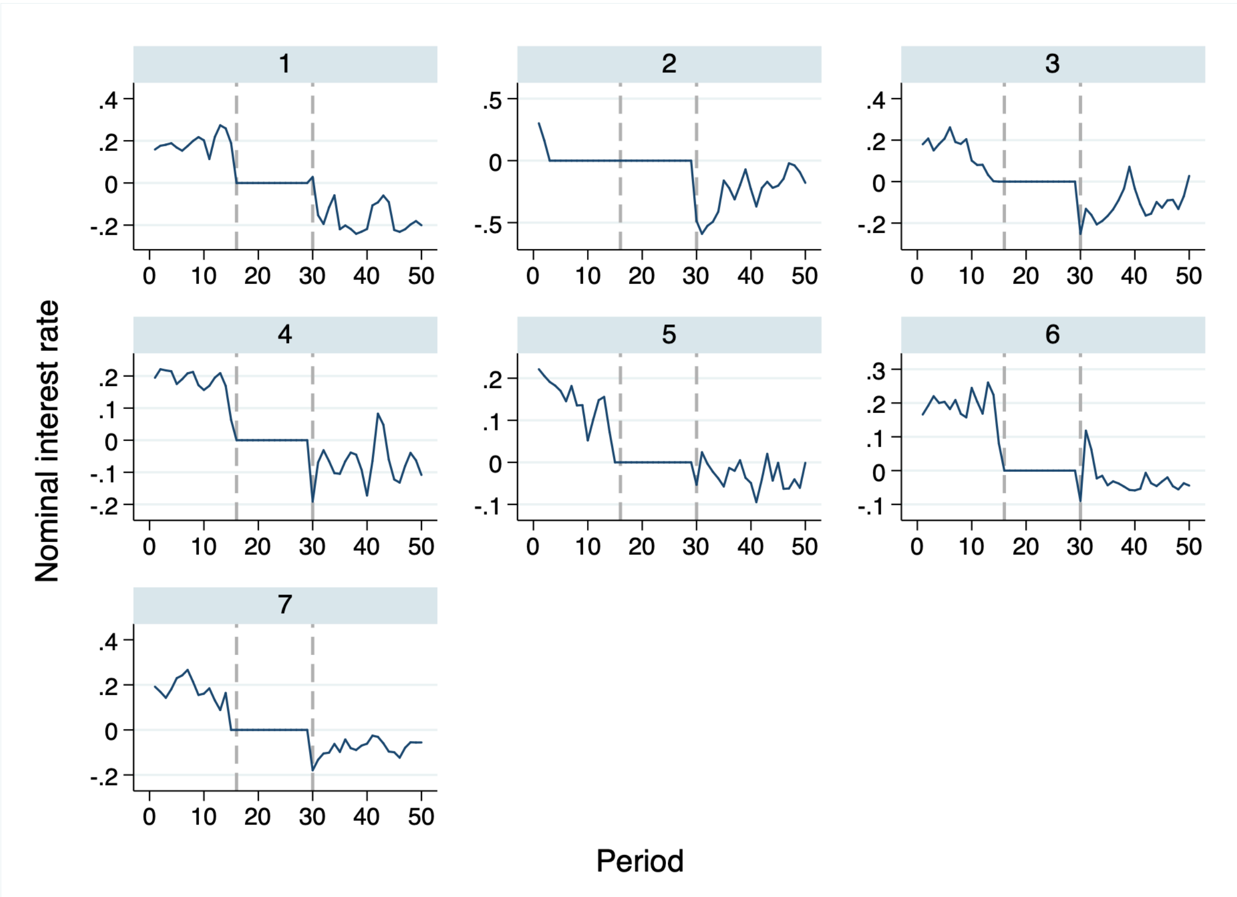

Figure 15: Nominal interest rates by session for *NegativeIR*

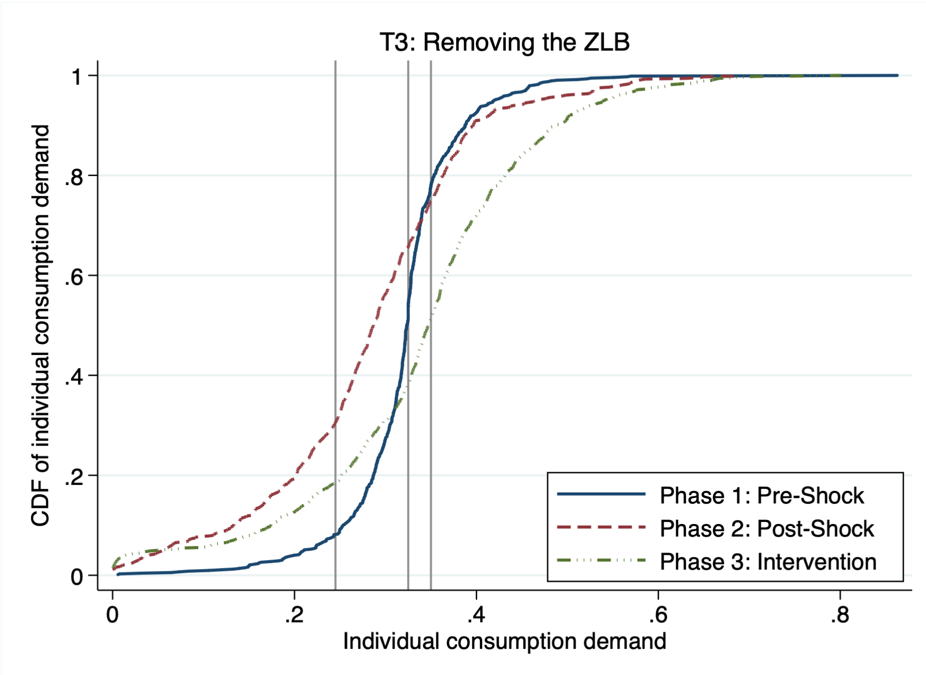

Figure 16: CDFs of consumption for all subjects and all periods for *NegativeIR*

Eliminating the ZLB consistently stimulates aggregate spending and stabilizes our experimental economies at the targeted full-employment equilibrium. Though our experimental economy is devoid of some features that might reveal downsides to such an intervention (an ability for bank runs, for example) there is scope for agents to either misunderstand the implication of negative rates or, conversely, to experience a more severe wealth effect from negative interest rates and cut their spending further. We do not observe evidence of either

Looking at Figure 15 gives a sense of the magnitude of negative rates used by the central bank to return these experimental economies to the full-employment equilibrium. We see in each experimental economy that nominal rates drop significantly in the intervention period and then revert almost instantly to a level much closer to zero. However, it is clear that, for most economies, the central bank is only capable of supporting the full-employment equilibrium by maintaining negative rates.

Figure 16 shows CDFs of consumption demand for *NegativeIR*. As was true with *Baseline* and *HigherTarget*, we again see that subjects consume optimally on average in Phase 1 and over consume in Phase 2. Now, unlike in *HigherTarget*, we see that consumption in Phase 3 is, on average, optimal. However, like in Phase 1 of all treatments, we see a large amount of heterogeneity in consumption.

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)).

Next, we can assess how the shocks and interventions alter the heterogeneity in subjects' forecasting heuristics. The different heuristic models we consider are listed below in Table 2. We focus our analysis on the forecasts related to concurrent inflation.

Model Class	**Heuristic Name**	**Model**
M1	Target	$E_{i,t}\pi_t = \pi_t^*$
M2	Naive Inflation	$E_{i,t}\pi_t = \pi_{t-1}$
M3	Constant Gain	$E_{i,t}\pi_t = E_{t-1}\pi_{t-1} + \gamma(E_{i,t-1}\pi_{t-1} - \pi_{t-1})$
M4	Trend-chasing	$E_{i,t}\pi_t = \pi_{t-1} + \tau(\pi_{t-1} - \pi_{t-2})$
M5	Naive Price	$E_{i,t}P_t = P_{t-1}$

Table 2: Inflation forecasting heuristics

M1 Target assumes that a subject bases her price forecast on the assumption that inflation today will equal the central bank's inflation target. Given the non-stochastic nature of the environment, this is a rational expectations equilibrium. M2 Naive Inflation assumes that a subject bases her price forecast on the assumption that inflation today will equal inflation yesterday. M3 Constant Gain assumes that a subject forms a price forecast today by updating yesterday's inflation expectation based on yesterday's inflation expectation error. Given this formulation, we consider a range of parameterizations of $\gamma \in [-1.5, -0.1]$. M4 Trend-chasing assumes that a subject's inflation forecast is an extrapolation of yesterday's inflation based on the recent trend in inflation. Given this formulation, we consider a range of parameterizations $\tau \in [0.1, 1.5]$. M5 Naive Price assumes that a subject forms a price expectation today based solely on yesterday's price.

We classify a subject by comparing, in each period, her price (or implied inflation) expectation for today to the price forecast arising from each of M1-M5. We then calculate the mean absolute error for each hypothetical heuristic (and for each parameter value for M3, M4) and classify participants as belonging to the heuristic that has the minimum RMSE.[15]

EMR's theory assumes that subjects are perfectly rational when forming price expectations. This, ex ante, seemed like an extreme assumption that could possibly form a wedge that would prevent the predictions of this model from mapping into reality. This assumption was relaxed by Gibbs (2017) who shows that the predictions of this are E-stable and thus survive, under a form of least squares learning.

We observe consistent heuristics in Phase 1 of all treatments. Trend-chasing is the dominant heuristic capturing 43-61% of participants' forecasting behavior. Forecasting according to the central bank's target and constant-gain heuristics describe a small minority of participants. We do not observe purely naive inflation forecasts, and only a small number of participants who forecast prices naively.

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 three treatments (from 34% to 12% in *Baseline*, 16% to 6.3% in *HigherTarget*, and 27% to 2% in *NegativeIR*), and 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. Rather, constant-gain learning becomes the dominant heuristic as participants grapple with forecasting in an unfamiliar environment. This comes at a significant reduction in trend-chasing heuristics.

[15]Note that M3 is equivalent to M2 for $\gamma = -1$. In the case that participants were classified in both, we assign their type to be M2 Naive Inflation.

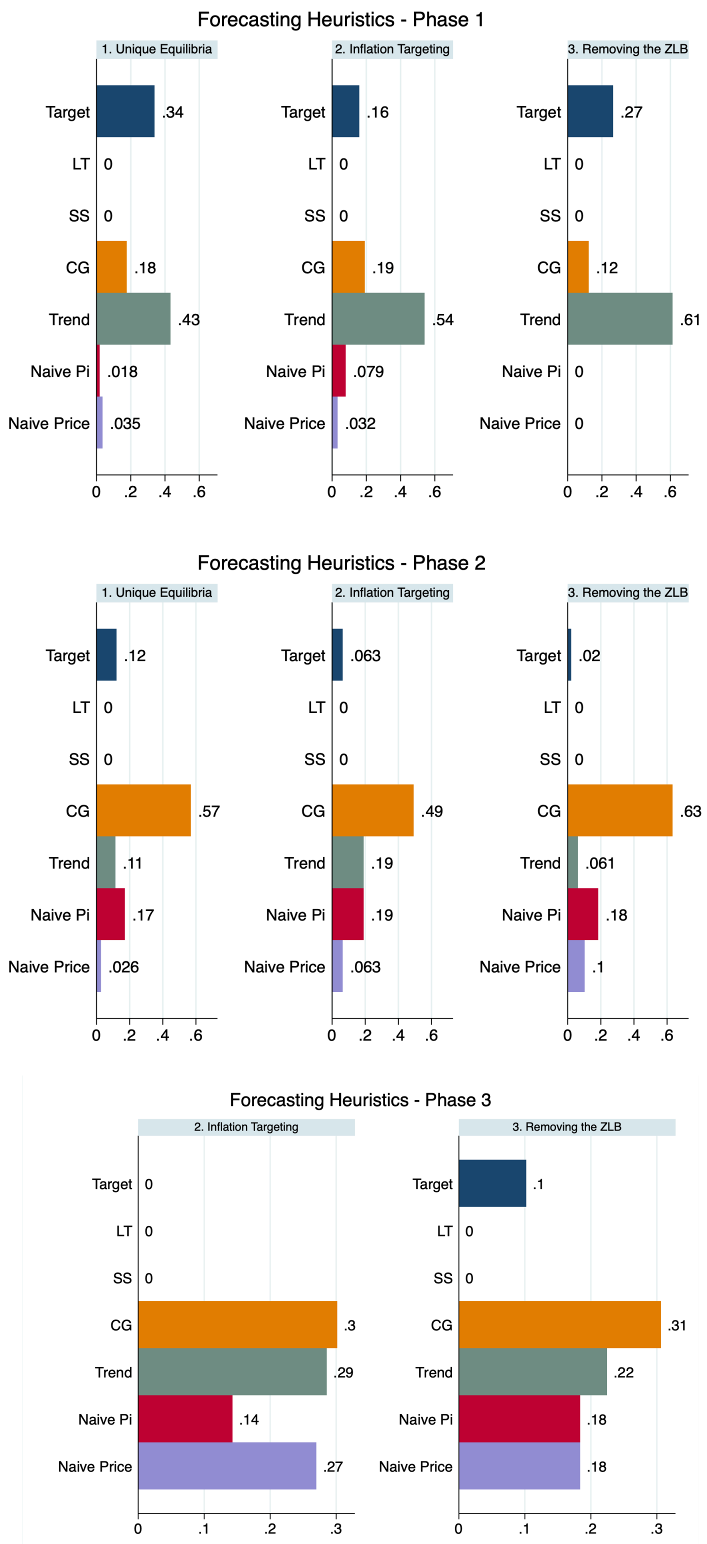

Figure 17: Forecasting heuristics by phase and by treatment

Increasing the inflation target in Phase 3 does not increase the share of participants using the central bank's target (the share falls to 0%). That is, no participant perceived the central bank's new inflation target of 30% as credible. The most striking change is the increase in share of participants simply forecasting based on last period's price, i.e. forecast zero percent inflation. We observe the proportion of naive price forecasts increase from 2.6% in Phase 2 to 27% in Phase 3, consistent with increased confusion about the environment. Trend-chasing heuristics also become more prevalent, with their share of the population rising from 11% in Phase 2 to 29% in Phase 3.

When the central bank eliminates the ZLB in *NegativeIR* more participants are willing to utilize the central bank's 10% inflation target as their forecast. This is still less than what we observe in Phase 1, suggesting that some of the credibility loss associated with the experience at the ZLB is permanent. The distribution of forecasting heuristics otherwise appears quite comparable to that of *HigherTarget*.

6 Conclusion

We experimentally investigate the ability of unconventional monetary policies to alleviate secular stagnation at the zero lower bound. Using the overlapping generations structure of Eggertsson, Mehrotra, Robbins (2019) as the model for our experimental economy, we find that EMR's model is robust to deviations from rationality along several dimensions. First, we see that the equilibria predicted by this model obtain even when economic agents form expectations using heuristics that are much less sophisticated than rational expectations and least-squares learning as explored by Gibbs (2017). Second, we see that the high inflation equilibrium equilibria are relatively robust to deviations away from optimal consumption profiles. However, systematic over-consumption driven by Pigouvian wealth effects can prevent an economy reaching the secular stagnation equilibrium following a deleveraging shock.

We find that deleveraging shocks consistently produce results that qualitatively match the model's description and, across all treatments, often triggers secular stagnation. However, central bank interventions via inflation targeting 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. Removing the zero lower bound and allowing interest rates to become negative, on the other hand, reliably returns our experimental economies to the full-employment, inflationary equilibria. Our results suggest that policies aimed at stimulating aggregate demand through increased real wealth balances are more effective than those relying on rational expectations.

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