Escaping Recessions*

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Abstract

We present new evidence that unconventional monetary policy works more effectively during recessions through wealth and substitution effects than through the expectations channel. We expose experimental economies to permanent deleveraging shocks that consistently induce deep and protracted recessions. The central bank intervenes by either permanently increasing its inflation target or using negative policy rates. Increasing the inflation target is non-credible, and neither generates inflationary expectations nor stimulates consumer demand. However, negative rates produce an immediate demand response that spikes inflation, which induces backward-looking agents to form inflationary expectations. Wealth and substitution effects restore output to potential and inflation to target.

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1 Introduction

A decades-long decline in the natural rate of interest has forced monetary policy makers to confront the new reality of combating recessions in low- or zero-rate environments (Laubach and Williams, 2003, 2016; Williams et al., 2016; Holston et al., 2017). Recessions are becoming longer and more frequent as there is little-to-no room for conventional policy to intervene during economic downturns. Rapid policy innovation during the Great Recession led to now-standard tools like forward guidance and quantitative easing. However, concerns about the limits of central bank balance sheet expansion and forward guidance necessitate new strategies (McKay et al., 2016; Campbell et al., 2019; Acharya and Rajan, 2022).

A leading contender in this debate is to simply increase the central bank's inflation target. During a prolonged recession, a higher inflation target is predicted to stimulate inflation expectations and, in turn, aggregate demand (Eggertsson et al., 2019c; Williams et al., 2016). This would have the added benefit of maintaining an otherwise effective policy framework. Another alternative is to allow interest on deposits to become significantly negative. Negative interest rates remove the restrictions imposed by the zero lower bound (ZLB hereafter), and if allowed to adjust as necessary, would spur household spending to avoid the erosion of interest-bearing savings (Kocherlakota et al., 2019; Agarwal and Kimball, 2015).

Both policies remain largely untested. Most countries keep their targets constant or lower them as inflation becomes better managed. Two exceptions are the Bank of Japan and Reserve Bank of New Zealand who had mixed success raising their targets (Nakata, 2020). While the ECB and other Eurozone countries have implemented negative rates, these have been cautiously mild (the lowest being $-.75\%$ by Danmarks Nationalbank and Swiss National Bank) with minimal pass-through to household deposits. Furthermore, policymakers face potentially important limits to the guidance they can glean from theory. The equilibrium selection problem generated by the ZLB and the reliance on the assumption that agents are rational make it difficult to predict the success of such policies in practice.

We overcome these empirical and theoretical limitations by designing a novel experimental macroeconomy that allows for the test of policy. Participants in our experiment play the role of households who interact together with automated firms and a monetary authority. To this end, we blend together production economy experiments (Lei and Noussair, 2002; Noussair et al., 1995, 1997, 2007, 2021) with Learning-to-Forecast experiments (Hommes, 2021).[1] This paper is one of

[1]Learning-to-Forecast Experiments (LtFEs), initiated by Marimon and Sunder (1993, 1994) and developed by

relatively few experiments that combines the production economy and LtFE approaches (Bao et al., 2013; Petersen, 2016) and the first to study consumption-saving behavior at the ZLB.

Participants play the role of household-consumers and interact in 50 periods of an overlapping generations framework. They inelastically supply labor and make repeated consumption-saving decisions for their current middle-aged and future old-aged selves. Participants also submit incentivized price forecasts about current and future aggregate prices. Importantly, our experimental framework produces individual-level data connecting incentivized inflation expectations and consumption-saving decisions. The simultaneous collection of this rich data provides key insights into the transmission of monetary policy and why certain policies work and fail.

We study participants' individual and aggregate behavior during times of economic stability and as the economy faces a lengthy recession caused by a permanent deleveraging shock and worsened by a binding zero lower bound on interest rates. Using a between-subject experimental design, we examine how higher inflation targets and negative interest rates can alleviate economic stagnation at the ZLB. We base the design of our experimental economies on Eggertsson et al. (2019c), which can produce a multiplicity of equilibria at the ZLB and captures the ongoing concern about declining natural rates that limit the scope of conventional policy. Thus, our experiment is capable of providing new empirical evidence on the learnability of equilibria at the ZLB (Benhabib et al., 2001; Evans et al., 2008; Benigno and Fornaro, 2018; Christiano et al., 2018; Arifovic et al., 2018; Gibbs, 2018), as well as the efficacy of higher inflation targets (Krugman, 2014b; Kocherlakota et al., 2019; Nakata, 2020), and negative interest rates (Altavilla et al., 2019; Heider et al., 2019; Eggertsson et al., 2019a).

Our *Baseline* treatment studies the transition of an economy from a targeted high inflation steady state to the secular stagnation steady state following a permanent deleveraging shock. The secular stagnation equilibrium is characterized by binding ZLB, permanent deflation, and an output gap. In three policy treatments, we extend our *Baseline* environment to allow for monetary policy interventions. After a lengthy episode at the ZLB, we introduce either a permanently higher inflation target (*HigherTarget*) or allow for negative interest rates (*NegativeIR* or *Nega-*

Heemeijer et al. (2009); Hommes (2011), are used to study expectation formation in financial and macroeconomic settings. See Hommes (2021) for an extensive overview of the literature. In LtFEs, participants' aggregate expectations determine automated demand decisions of traders and aggregate price outcomes. This framework has been used extensively to study questions related to monetary policy implementation and communication (Pfajfar and Žakelj, 2014; Cornand and M'baye, 2018; Pfajfar and Žakelj, 2016; Kryvtsov and Petersen, 2021; Assenza et al., 2021; Hommes and Makarewicz, 2021; Rholes and Petersen, 2021; Petersen and Rholes, 2022), and more specifically at the ZLB (Arifovic and Petersen, 2017; Hommes et al., 2019; Kostyshyna et al., 2021; Ahrens et al., 2017).

tiveIR+Portfolio) in an effort to stimulate inflation expectations and household demand.

In the *Baseline* treatment, we observe economies behaving in line with the rational equilibrium predictions of the model. During the initial phase of our experiment, most economies converge to the targeted high inflation steady state. Exogenous deleveraging shocks consistently generate pessimistic expectations and manufacture various degrees of instability that produce permanent deflation and push economies toward the secular stagnation steady state.

In the *HigherTarget* treatment, the central bank intervenes in the protracted recessions by permanently increasing its inflation target. This creates a multiplicity of locally-determinate steady states: two full-employment steady states (one at the new higher inflation target and a lower-inflation liquidity trap) as well as a secular stagnation steady state. We find that permanently increasing the inflation target does not effectively return any of our experimental economies to the high inflation or liquidity trap equilibria. Even though the central bank is committed to maintaining higher inflation, participants do not perceive the new target as credible. Consumption decisions, and consequently inflation, do not increase sufficiently on impact of the announced policy change. The central bank's failure to achieve its new target increases pessimism that drives the economies toward the secular stagnation equilibrium.

In the *NegativeIR* treatment, the central bank instead implements negative interest rates to combat demand-driven recessions. In theory, removing the ZLB reshapes the aggregate demand curve, eliminates the rational-expectations secular stagnation equilibrium and restores the unique full-employment equilibrium. We find that negative interest rates work as expected. Participants react strongly to the prospect of their wealth being taxed away by negative saving rates. Consumption increases significantly on impact, which in turn produces inflation and encourages more inflationary expectations in subsequent periods. These economies converge quickly to the unique full-employment equilibrium that coincides with the central bank's inflation target.

An oft-cited concern about negative interest rates is that households would circumvent negative deposit rates by shifting their wealth into other assets (Agarwal and Kimball, 2015; Kimball, 2015). Our *NegativeIR+Portfolio* treatment embeds *NegativeIR* and introduces a portfolio choice that allows us to test this concern. Participants may either hold their wealth in one-period interest-bearing bonds or cash that pays no interest. We find that results from *NegativeIR* are robust to introducing a portfolio choice. Both the mechanism and dynamics of recovery in *NegativeIR+Portfolio* closely match those observed in *NegativeIR*, except that the stimulative effects of negative rates occur with a lag. When nominal interest rates first become negative, nearly twothirds of participants previously in bonds switch to cash. Neither type of asset holder changes their spending meaningfully. However, by the next period, the average share of net income spent on current consumption increases by 22 p.p. as savers learn the consequences of large negative interest rates on their wealth. We attribute participants' *wait-and-see* behavior to the combination of high strategic complementarities increased cognitive load associated with making an additional portfolio decision.

The broad takeaway from our paper is that policies that influence wealth directly are more effective than those that operate solely through the expectations channel. Following a lengthy period of low inflation or deflation, raising the inflation target to stimulate expectations demands too much credibility to be successful. People "need to see it to believe it", especially when they rely heavily on recently-experienced inflation to form their expectations (Malmendier and Nagel, 2016) or central bank credibility (McMahon and Rholes, 2022). Despite early policy success, the central bank's credibility quickly evaporates as it fails to stymie recession. Participants do not believe that the central bank is capable of producing its promised higher inflation when it fails to achieve its original target. To spur on inflation expectations, the central bank needs to produce inflation. In our experiment, this is best accomplished by propelling household consumption via negative interest rates.

Behavior deviates from the the predictions of our rational benchmark model in important ways. First, expectations do not blindly follow the central bank's inflation target. Rather, the majority of participants rely on historical data, personal forecast errors, and trends to formulate their forecasts. Reliance on the inflation target evolves with the central bank's performance in achieving its target. This sort of heterogeneity and forecast-switching behavior has been well-documented in LtFEs. See for example Kryvtsov and Petersen (2013); Arifovic and Petersen (2017); Pfajfar and Žakelj (2014); Hommes et al. (2019); Cornand and M'baye (2018). Importantly, our paper provides further evidence that monetary policy prescriptions involving the expectations channel need to rethink their assumptions. Allowing for more realistic backward-looking expectations and the potential loss of central bank credibility can significantly mute the efficacy of ZLB strategies such as raising the inflation target.

We contribute to an ongoing debate in the literature about whether real decisions respond to expectations (i.e. do people operate along their Euler equation). The evidence on this is mixed (Binder and Brunet, 2022) with some authors finding support for a theory-consistent relationship (D'Acunto et al., 2016; D'Acunto et al., 2018) and others finding either no relationship or an opposite relationship (Binder and Brunet, 2022; Bachmann et al., 2015). Consistent with theory, we find that demand responds strongly to inflation expectations. However, participants primarily rely on market-based expectations when making consumption decisions, suggesting there is a strong social component to this relationship. Further, whenever deleveraging shocks generate aggregate instability, this link weakens as participants rely more heavily on their individual-level expectations. Overall, we see that instability weakens the link between expectations and real decisions. Our results suggest that a potential cost of de-anchored expectations is a weakening of the link between expectations and decisions, which could undermine stabilization efforts via policy driven through the expectations channel.

Consumption-saving behavior also deviates notably from standard theory. We first observe significant habit persistence in terms of the share of net income consumed. Second, many participants who faced negative interest rates in *NegativeIR* and *NegativeIR+Portfolio* choose to save more (rather than less). We also observe 40-50% of participants in *NegativeIR+Portfolio* persistently making irrational portfolio decisions, i.e. investing in bonds when returns are expected to be negative and cash when bond yields are positive. We attribute this investment behavior to a mix of inattention and uncertainty about policy rates.

We also observe considerable consumption heterogeneity despite the provision of common information about market-expected inflation and interest rates. This heterogeneity worsens following the permanent deleveraging shocks. Importantly, negative rate policies that restore output, employment, and inflation to their steady state levels cannot effectively reduce consumption heterogeneity to pre-shock levels. This persistent consumption heterogeneity leads to a meaningful increase in inequality and welfare loss, even after controlling for corresponding declines in production, and both realized and expected inflation volatility. This result demonstrates empirically the importance of capturing heterogeneity (for example, Hausman and Newey (2016)) in order to fully understand the implications of policy.

The rest of the paper is organized as follows. Section 2 lays out the theoretical framework and hypotheses for our experiment, and Section 3 provides details of the experimental implementation. Section 4 presents our experimental results, and is followed by a discussion of the impact of unconventional policy on forecasting heuristics and demand in Sections 5 and 6. Section 7 discusses factors driving our findings and Section 8 concludes.

2 Theoretical Framework and Hypotheses

We build our experimental economies using the three-period OLG model of secular stagnation introduced in Eggertsson et al. (2019c). This section outlines the model, explains how decisions from our participants influence the evolution of our economies, and lays out our testable hypotheses.

Households

Our experimental economies feature young, middle-aged, and old households where the population size of each is stable over time. Households derive utility from a single consumption good, C_t for each period t. Young households earn no income and may borrow up to a fraction, D_t, of their middle-aged income to consume. Middle-aged households earn income from their inelastic provision of labor, $\overline{L}$, and from firm profits Z_t. These households repay debt accrued while young, and then split remaining income between consumption and savings. Old households consume all their savings. A one-period, risk-free bond facilitates lending and borrowing between middle-aged and young households in the loanable funds market. The central bank controls the per-period nominal rate of return, i_t, on this asset. Thus, households maximize:

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

subject to the following budget constraints:

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

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

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

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

where W_t represents the nominal wage, P_t represents the aggregate price level, and B_t^y and B_t^m represent the borrowing of the young and savings for the middle-aged. Equation (3) implies that D_t is always binding, while Equation (5) implies that old households consume all wealth. This maximization problem yields the Euler equation

$$\frac{1}{C_t^m} = \beta \mathbb{E}_t \frac{1}{C_{t+1}^o}(1+i_t)\frac{P_t}{P_{t+1}} \tag{6}$$

Firms

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

$$\frac{W_t}{P_t} = \alpha L_t^{\alpha-1} \tag{7}$$

where α governs the marginal productivity of labor. The model includes wage rigidity as the key source of market friction. Wages in each period t are a convex combination of the flexible wage $W^{flex} = \alpha P_t L_t^{\alpha-1}$, and wages from the previous period, W_{t-1}, and are given by

$$W_t = max\{W_t, W_{t-1} + (1-\gamma)W^{flex}\} \tag{8}$$

where $\gamma \in [0,1]$ represents the degree of nominal wage rigidity. W_t equals W^{flex} unless the economy is experiencing deflation.

Central Bank

The central bank sets nominal interest rates according to a Taylor-type monetary policy rule

$$1 + i_t = max\left(1, (1+i^*)\left(\frac{\Pi_t}{\Pi^*}\right)^{\phi_\pi}\right) \tag{9}$$

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 $\Pi_t = \frac{P_{t+1}}{P_t}$.

Equilibrium

The existence of downward wage rigidity creates a kink in the aggregate supply curve. If an economy faces deflation, wage rigidities lead to labor rationing and an output gap (Equation (11)).

When the economy experiences inflation, there is full employment and $Y_t = \overline{L}^{\alpha} = Y^f$ (Equation (10)). Aggregate supply (AS) is then split into two segments:

$$Y_t = \overline{L}^{\alpha}, \qquad \Pi \geq 1 \tag{10}$$

$$Y_t = Y_f \left(\frac{\gamma - \Pi}{\Pi(\gamma - 1)} \right)^{\frac{\alpha}{1-\alpha}}, \qquad \Pi < 1 \tag{11}$$

where Equation (10) describes the vertical portion of the AS curve and Equation (11) the upward sloping portion of the AS curve. The presence of the ZLB on nominal interest rates also creates a kink in the aggregate demand curve. At the ZLB, increases in the magnitude of deflation lead to a higher real interest rate, which increases the opportunity cost of consumption. Aggregate demand (AD) is then split into:

$$Y = D + \frac{(1+\beta)(1)D}{\beta} \frac{1}{\Pi^{\phi_\pi - 1}} \frac{(\Pi^*)^{\phi_\pi}}{(1+i*)}, \qquad i > 0 \tag{12}$$

$$Y = D + \frac{(1+\beta)(1)D}{\beta} \Pi, \qquad i = 0 \tag{13}$$

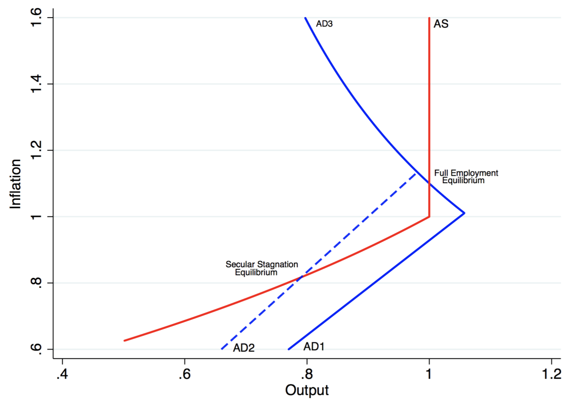
where Equation (12) is the downward sloping portion of AD and Equation (13) the upward sloping portion of AD.

Hypotheses

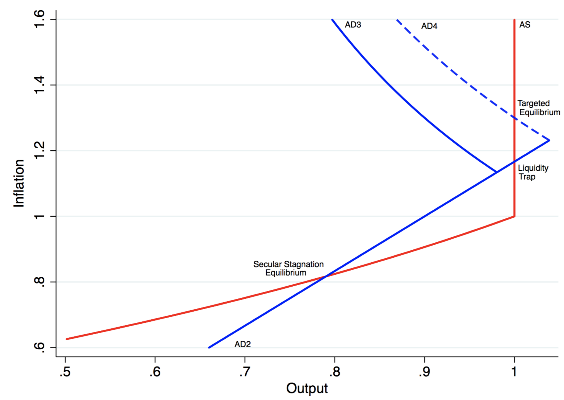
We now present testable hypotheses of the model based on the parameterizations we employ in our laboratory experiments. We assume that $\Pi^* = 1.1, \phi_\pi = 2, \gamma = .3, Y_f = 1, \alpha = .7, \beta = 1, L = 1$.

Suppose an inflationary economy faces a permanent deleveraging shock that reduces the amount of money that young households may borrow for consumption. This results in 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. We illustrate the impact of such a shock on steady-state levels of output and inflation in Figure 1a.

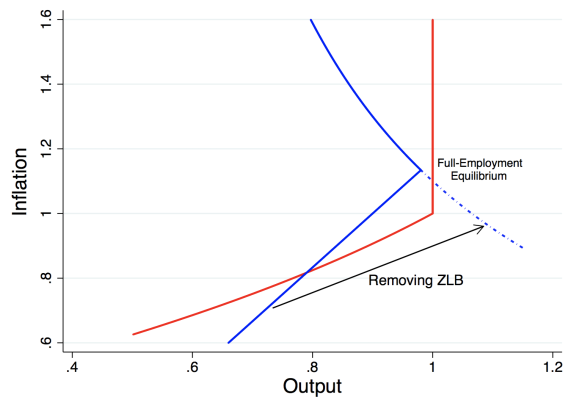
A deleveraging shock impacts both segments of AD. However, a simultaneous adjustment of i^*



(a) Deleveraging shock



(b) Increased inflation target



(c) Removing the ZLB

Figure 1

in Equation (12) offsets the shock so that only the upward sloping portion of the AD shifts significantly. Importantly, shocks to D can eliminate a unique inflationary equilibrium and create a unique 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 1a. A deleveraging shock reduces the borrowing constraint to $D = 30\%$, which shifts the upward sloping demand curve inward and yields a unique secular stagnation equilibrium where AD2 intersects AS. Thus, our first two testable hypotheses:

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 unique secular stagnation equilibrium.

The central bank, facing a binding ZLB on its policy rate, addresses secular stagnation by permanently increasing its inflation target from $\Pi^* = 10\%$ to $\Pi^* = 30\%$. This shifts AD3 rightward to AD4 in Figure 1b, introducing two new rational expectations 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). This yields our third testable hypothesis

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

Increasing the inflation target from 10 to 30% is arguably extreme but serves a few 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 through the expectations channel (Sims, 2003; Gabaix, 2020).

The limited available empirical evidence 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 (2014a). 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".

We also study the use of negative nominal interest rates to combat secular stagnation. The idea of using negative policy rates has gained in popularity over the last two decades as many advanced- and emerging-economy central banks have found themselves constrained by the ZLB. There is some evidence that banks may be able to successfully employ negative rates (Eggertsson et al., 2019b; Altavilla et al., 2019).

Eliminating the ZLB removes the kink in the AD curve, so that AD is fully described by Equation (12). We show in Figure 1c that this change eliminates the unique secular stagnation equilibrium and restores the full-employment equilibrium that coincides with the central bank's 10% inflation target. This leads to our fourth testable hypothesis:

H4. Allowing the central bank to use negative nominal interest rates moves an economy out of secular stagnation and back to the targeted inflationary equilibrium.

Finally, we study how households' portfolio decisions respond to negative interest rates. To do this, we consider a simplified setting where households can choose to hold either cash or bonds. This provides evidence on how households' real decisions and demand for cash respond to negative policy rates, which is missing in observational data. This is because in countries where central banks set negative interest rates, few if any commercial banks passed those rates onto depositors out of concern it would spur 'bank runs'.[2]

Our last hypothesis supposes 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 ZLB is binding. This effectively reintroduces the kinked aggregate demand curve and the secular stagnation equilibrium as in Figure 1a.

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

3 Experimental Implementation

Each laboratory session is an independent economy consisting of seven young, seven middle-aged, and seven old households interacting in our three-period overlapping generations framework. For simplicity, we automate the young and old agents to behave in a theory-consistent manner. We focus our attention on the behavior of the middle-aged households, played by participants, who set a household's current period spending and saving. These design decisions reduce the complexity of our experimental environment while still capturing how policy operates through expectations and intertemporal choice. We provide more details of the automation in Online appendix A.

Timing

[2]Eisenschmidt and Smets (2019) show that the distribution of household deposit rates is truncated at zero following the 2014-2017 implementation of negative interest rates by the ECB.

The experiment consists of 30 to 50 decision periods (depending upon treatment) and each decision period consists of three stages. Instructions with screenshots can be found in Online appendix B.

Stage 1: All participants simultaneously submit a nowcast about the current price, $E_{i,t}P_t$ and a forecast about the subsequent period's price, $E_{i,t}P_{t+1}$. Subjects also submit a qualitative nowcast about the change in the nominal interest rate relative to the previous period (increase, stay the same, decrease).

Stage 2: Participants, playing the role of middle-aged households, receive information about the current period's expected net income after repaying debts accrued while they were young, the current period's expected nominal interest rate, and the current and next period's expected prices. Participants can use this information to make a consumption decision, $C_{i,t}$. Any savings are automatically spent in the subsequent period on consumption. Figure 2 shows the evolution of the OLG economy and how period t middle-aged household decisions impact their $t+1$ outcomes.

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 2: Co-determination of middle-aged and old spending

After all participants have submitted their spending decisions, we use the spending decisions of the automated young agents and the 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.

We compute aggregate spending in period t by summing the spending decisions of all middle-aged (determined in period t), old households (determined in period $t-1$), and the automated young participants (determined in period t). We use this information to clear markets, allocate output, and assign utility. Subjects earn points based on consumption utility and on forecast accuracy.

We face the challenge of simultaneously clearing markets and allowing the young to borrow from future uncertain income. We circumvent this issue using aggregate price expectations to determine income and interest rate signals, which can inform participants' decisions before markets clear. Coupling expectations with a novel pricing algorithm allows us to determine aggregate spending, price, wage, output, labor demand, and the interest rate in period t. The algorithm is described in detail in Online appendix C.

Stage 3: The third stage provides participants with summary information about the realized current-period outcomes. Participants observe the amount of output produced, the unit price of output, the nominal interest rate, and the amount of points earned from consumption.

Information

Participants are provided with detailed information about the structure of the OLG economy. In particular, they know the number of households of each type, the borrowing constraints and consumption decisions of the young households, an explicit function describing the central bank's monetary policy, and the central bank's inflation target. They receive qualitative information about the link between expectations, consumption spending, output and inflation, and are encouraged to use the software tools (described below) to make precise calculations. Participants are also informed that that all information, other than personal decisions and points, is common information.

We provide a history of all aggregate-level variables to subjects in all periods (following the first period) during both stages of each period. Additionally, the central bank announces the current inflation target during both stages of each period. In the NegativeIR and NegativeIR+Portfolio treatments, we pause the experiment in Period 30 before the start of Phase 3 and announce that the central bank has the ability to set negative nominal interest rates. In a new set of paper instructions, we explain how negative interest rates affect savings and debt and emphasize that this change in the policy rule is permanent.

We provide subjects with two tools to facilitate forecasting and decision-making. The first tool, available in Stage 1 of each period, allows subjects to convert between price and 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 subject's 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 consumption. 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.

Incentives

Participants earn utility 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 $U_it = 5 + ln(0.00673 + C_{i,t})$, so that if $C_{i,t} = 0$, $U_{i,t} = 0$. Each period t participants receive points based on their period $t-1$ and t decisions (with the exception of the first period where there was no previous decision). We incentivize price forecasts using the following payoff function, $ForecastPoints_t = 2^{-|E_tP_t - P_t|} + 2^{-|E_{t-1}P_t - P_t|}$

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. Each period subjects also earn two points for correct qualitative interest rate forecasts and zero points otherwise. We convert experimental points into real dollars at a rate of 20-to-1. This amounted to an average payoff of $34.50.

Procedures

The experiments were conducted at Texas A&M University with inexperienced participants drawn from a diverse subject pool, recruited with ORSEE (Greiner, 2015) from September 2018 to December 2021. The sessions were conducted in-person and lasted up to two hours of which instructions took 45 minutes, three practice periods took 15 minutes, and the paid experiment the rest. Participants were paid in cash prior to the pandemic and via e-transfer when the lab re-opened during the pandemic.

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 that the economy is operating along the steady-state inflation path. A surprise exogenous and permanent deleveraging shock creates 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 the full-employment equilibrium. Let π^{tgt}, π^{ss}, π^{lt} denote the following rational expectations equilibria: an inflationary steady-state equilibrium, a secular stagnation steady-state equilibrium, and a liquidity trap equilibrium, respectively.

Baseline

Baseline explores the transition of an economy from π^{tgt} to π^{ss}. This treatment features 30 periods of play divided into a 15-period pre-shock phase (Phase 1) and a 15-period post-shock phase (Phase 2). 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 start of Phase 2. This announcement informs subjects about the magnitude of this shock, how it impacts the economy, and that the shock is permanent. This is common information to all participants.

Policy treatments

Each subsequent treatment embeds *Baseline*, with the caveat that shocks in *HigherTarget*, *NegativeIR*, and *NegativeIR+Portfolio*, are from $D_t = .35$ to $D_t^{shock} = .3$. All policy interventions are announced verbally by the experimenter and are common information.

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 its permanent inflation target increase at the end of period 30.

NegativeIR: This treatment is identical to *Baseline* in Phases 1 and 2. Phase 3 begins following the removal of the ZLB after period 30.

NegativeIR-Portfolio: This treatment is identical to *NegativeIR* in terms of timing and policy intervention, but includes a portfolio choice.

We summarize the treatment predictions in Table 1 below.

	Sessions	Periods	Phase 1	Phase 2	Phase 3
Baseline	8	30	$\pi^{tgt} = 10\%$	$\pi^{ss} = -24.7\%$	N/A
HigherTarget	7	50	$\pi^{tgt} = 10\%$	$\pi^{ss} = -18.3\%$	$\pi^{tgt} = 30\%, \pi^{ss} = -18.3\%, \pi^{lt} = 16.7\%$
NegativeIR	7	50	$\pi^{tgt} = 10\%$	$\pi^{ss} = -18.3\%$	$\pi^{tgt} = 10\%$
NegativeIR+Portfolio	7	50	$\pi^{tgt} = 10\%$	$\pi^{ss} = -18.3\%$	$\pi^{tgt} = 10\%$

Table 1: Parameterized equilibria across treatments and phases

4 Results

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

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 3, 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 3 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 (discussed in detail in Section Section 5).

Introducing the deleveraging shock consistently generates deflationary episodes 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 that lead to real welfare losses.

This lack of convergence to the secular stagnation equilibrium is due to a combination of sluggish adjustments in expectations and consumption. Expectations adjust sluggishly following the deleveraging shock, leading to downward wage rigidity and a slower adjustment toward the sec-

Baseline Results

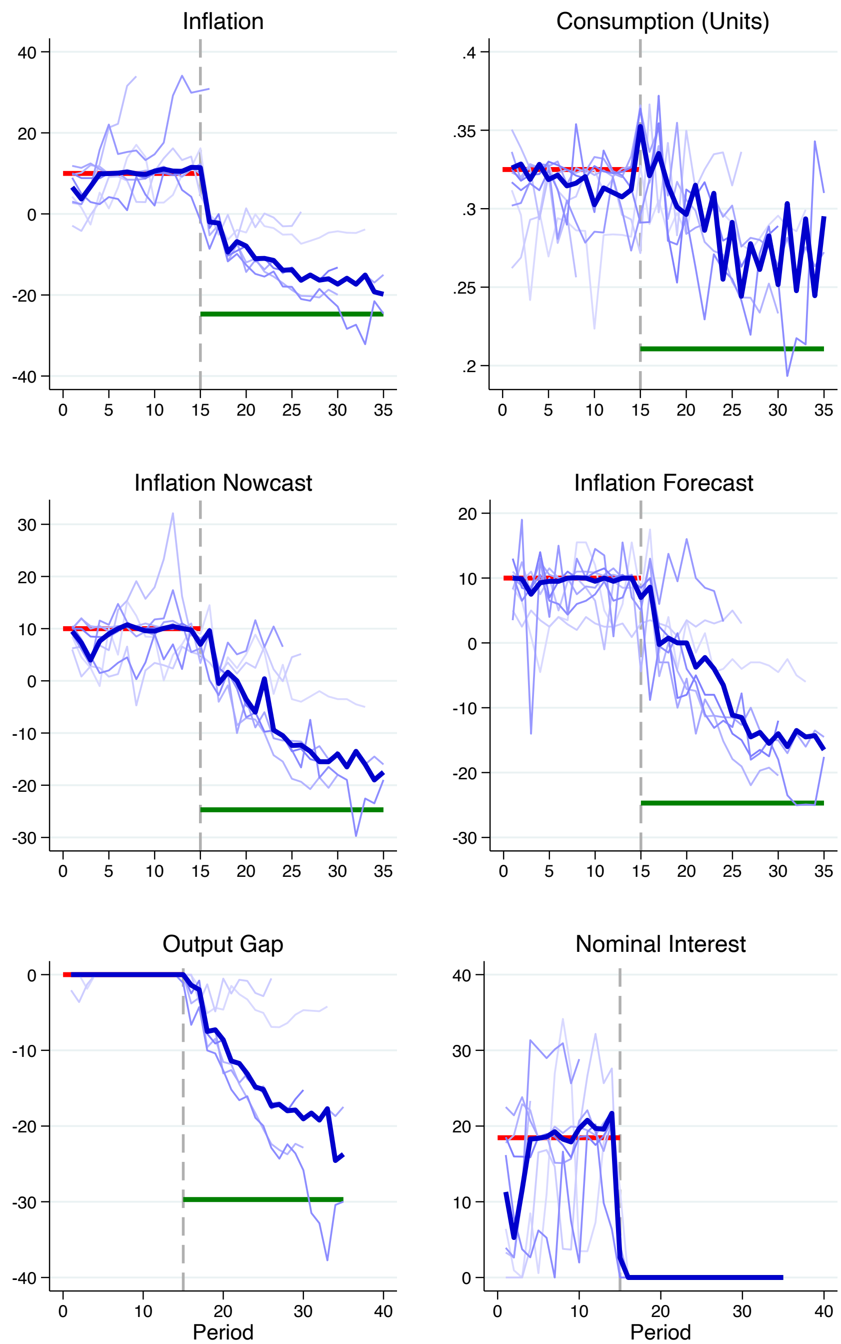


Figure 3: Results for *Baseline*. Light-blue lines represent session-level medians. Dark-blue lines represent treatment-level medians. All data are in percentage terms except for consumption, which is displayed in units demanded. Colored horizontal lines denote steady-state equilibrium values. Vertical 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.

ular stagnation equilibrium. This sluggish adjustment is exacerbated by over-consumption that occurs once subjects begin to experience deflation (Consumption sub-figure of Figure 3).

Interestingly, two of our experimental economies experience hyperinflation. Their time series are truncated due to scaling issues. This hyperinflation 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 shock, we do consistently create economic conditions that warrant intervention by generating deflation, consumption shortfalls, and output gaps.

HigherTarget

We now consider results from *HigherTarget*, which nests *Baseline* but also includes an intervention phase Phase 3) where the central bank addresses secular decline by permanently increasing 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. Instead, this intervention adds 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 problems even when theory cannot.

We show the results from *HigherTarget* in Figure 4. 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 leads to a treatment-level average consumption that falls well short of the targeted equilibrium level of consumption. This shortfall of inflation, inflation expectations, and consumption leads to a persistent output gap in most economies. In those few economies where the output gap does close in Phase 3, 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.

Subjects in the *HighterTarget* 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 and 2 is salient for our subjects.

Several *HigherTarget* economies in the post-intervention environment do manage to mitigate deflation by coordinating loosely on zero inflation. This is true despite there being no stable price equilibrium among the set of predicted rational expectations equilibria. In fact, EMR point out that such a steady-state is impossible in their model. 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.

HigherTarget Results

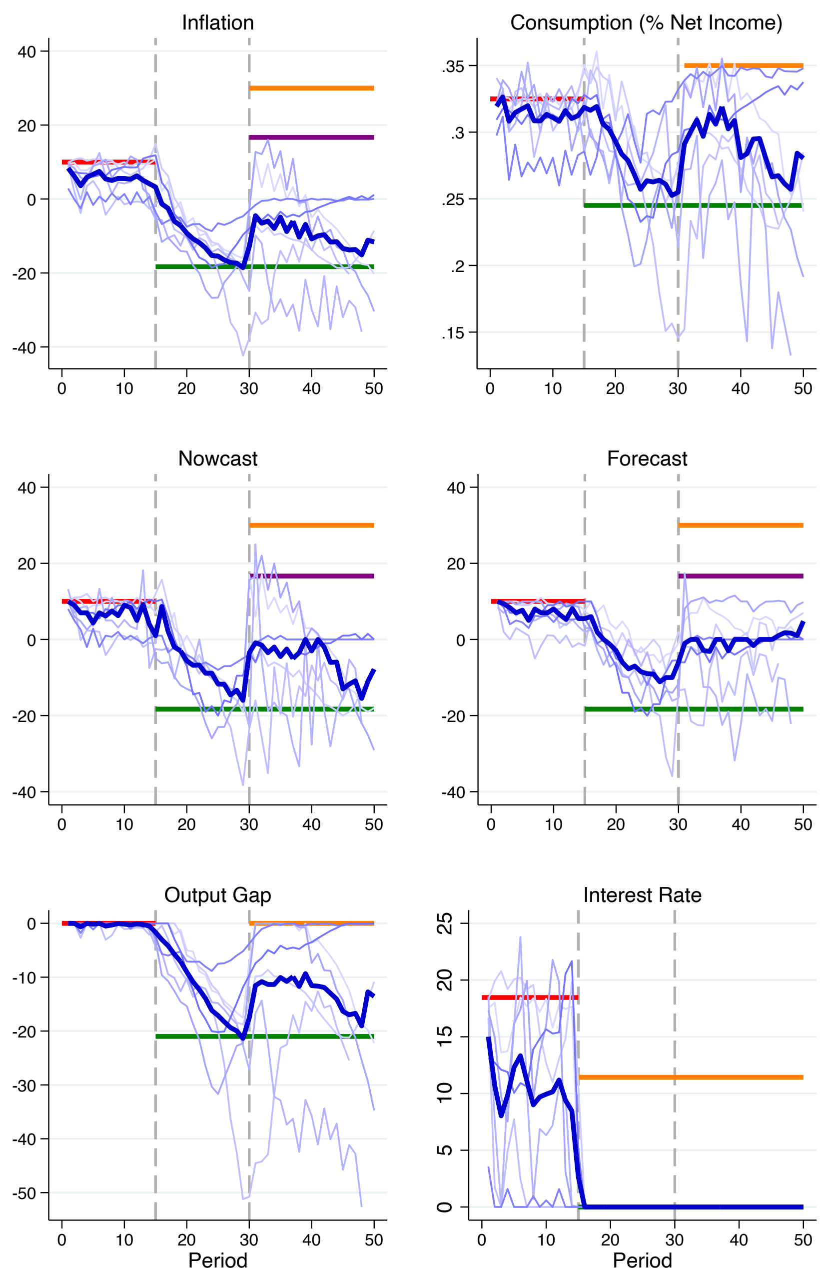


Figure 4: Results for *HigherTarget*. Light-blue lines represent session-level medians. Dark-blue lines represent treatment-level medians. All data are in percentage terms except for consumption, which is displayed in units demanded. Colored horizontal lines denote steady-state equilibrium values. Vertical 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.

NegativeIR

This subsection considers results from *NegativeIR*. This treatment differs from *HigherTarget* in that the mechanistic central bank now intervenes during deflationary episodes by implementing negative nominal interest rates rather than by increasing its inflation target. Crucially, the efficacy of this intervention does not hinge on primacy of 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.[3] Increased inflation should lead to higher inflation expectations. These two effects - increased inflation coupled with increased inflation expectations - should become reinforcing.

Under rational expectations, inflation expectations should react immediately to the central bank's inflation target in *HigherTarget*, which leads in increased consumption and increased inflation. Instead, we observe that it is increased consumption that leads to increased inflation, which in turn increases inflation expectations in *NegativeIR*.

Results from *NegativeIR* are shown in Figure 5. 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 ZLB removes the kink in the aggregate demand curve, thereby eliminating the secular stagnation equilibrium and restoring the unique targeted equilibrium present in Phase 1 of each treatment (as depicted in Figure 1c). As was true with experimental economies in *Baseline* and *HigherTarget*, we again observe convergence in Phases 1 and 2 toward the targeted and secular stagnation equilibria, respectively. Deleveraging shocks generate deflationary episodes with now-familiar session-level heterogeneity in the magnitude of deflation.

Figure 5 shows that our economies converge to the targeted equilibrium following central bank intervention. As one might expect, we see a sharp increase in consumption, which generates considerable inflation in the period immediately following the policy intervention. We also observe 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. Finally, implementing negative nominal rates also consistently closes the output gaps that emerged during Phase 2 of the *NegativeIR* ses-

[3]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 is below capacity, then spending in excess of whatever restores full production leads to inflation.

NegativeIR Results

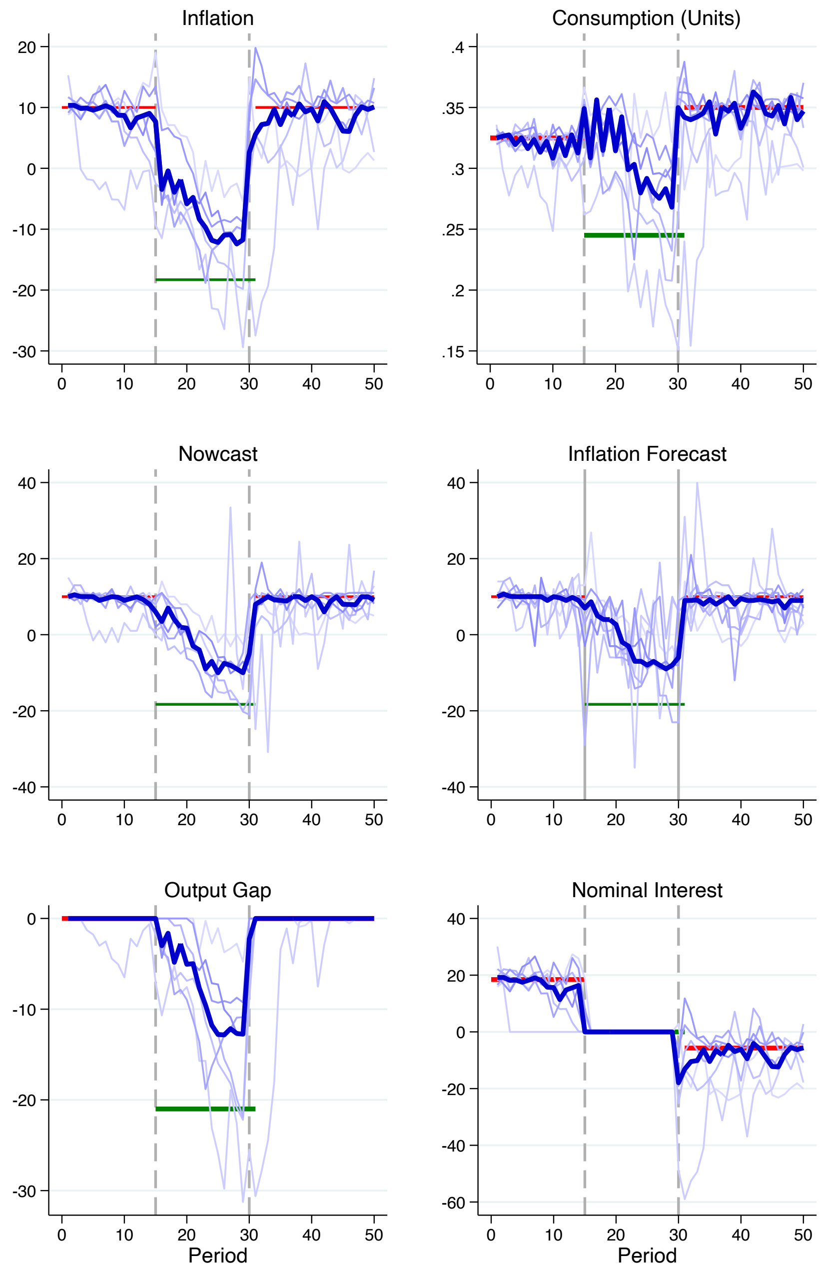


Figure 5: Results for *NegativeIR*. Light-blue lines represent session-level medians and the thicker. Dark-blue lines represent treatment-level medians. All data are in percentage terms except for consumption, which is displayed in units demanded. Colored horizontal lines denote steady-state equilibrium values. 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.

sions. This closure is both immediate and stable for all but a single experimental economy.

Also interesting here are Phase 3 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 3 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.

NegativeIR+Portfolio

An important real-world concern is that if commercial banks pass negative rates through 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 ZLB 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 through to household deposit rates whenever the ECB implemented negative nominal interest rates in the Euro area.[4]

On the other hand, subjects may also understand that negative rates are a 'necessary evil' that prevent deflation and an output shortfall. They 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. 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.

[4] We discuss this in more detail in Section Section 8.

NegativeIR+Portfolio Results

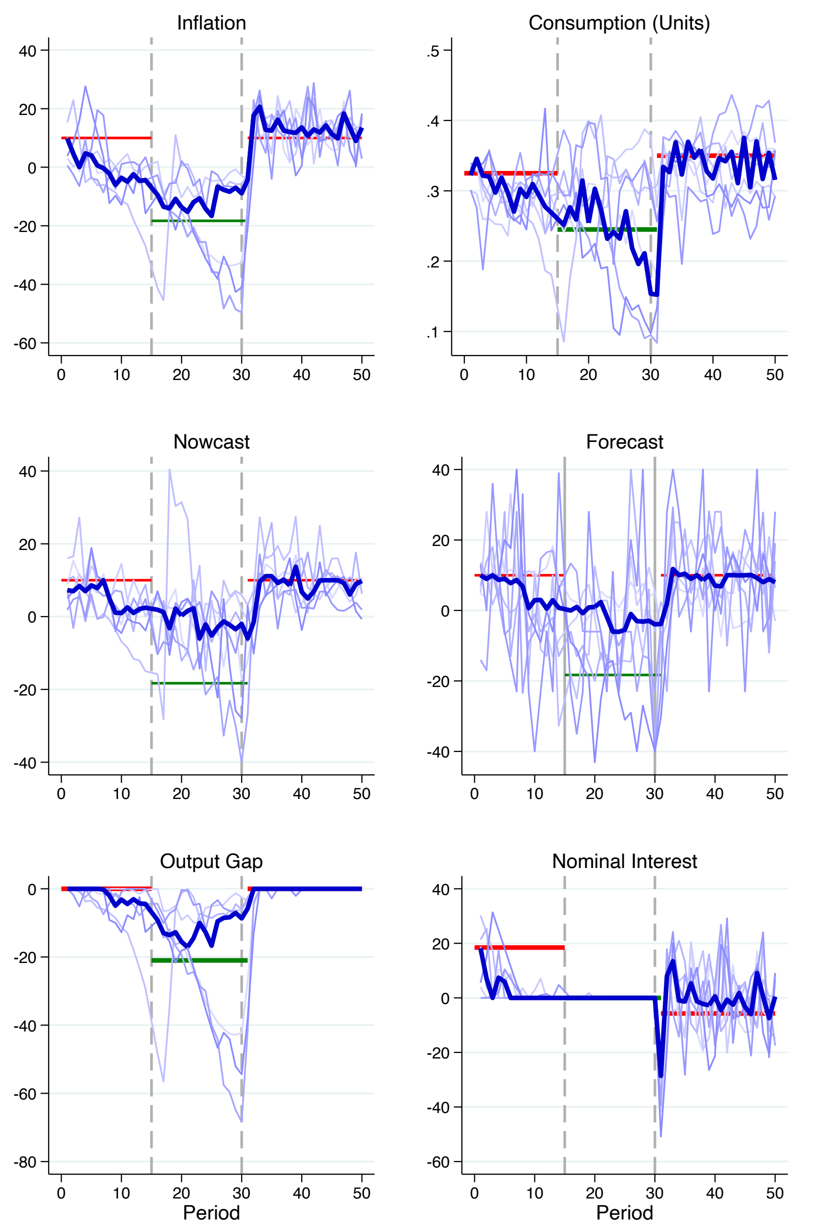


Figure 6: Results for *NegativeIR+Portfolio*. Light-blue lines represent session-level medians and the thicker. Dark-blue lines represent treatment-level medians. All data are in percentage terms except for consumption, which is displayed in units demanded. Colored horizontal lines denote steady-state equilibrium values. 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.

Results from *NegativeIR+Portfolio* are shown in Figure 6. 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 the high inflation steady state in Phase 1 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 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 next evaluate the convergence of the economies, for each phase, relative to our hypotheses. In Table 2 we report the mean inflation rate in the final three periods of each phase. We evaluate, for each treatment and phase, whether the mean inflation rate is statistically different from the predicted steady state. Asterisks denote significance at the 1% (***), 5% (**), and 10% (*) levels, respectively, based on Wilcoxon signed-rank and rank-sum tests ($N = 7$ in all tests).

Treatment	**N**	**Phase 1**	**Phase 2**	**Phase 3**
Baseline	7	13.13	-15.33**	
		(9.505)	(5.86)	
HigherTarget	7	4.14	-17.69	-9.73**
		(6.34)	(9.78)	(10.54)
NegativeIR	7	7.03	-13.05	8.59
		(6.79)	6.23)	(3.27)
NegativeIR+Portfolio	7	-6.87**	-19.60	12.00*
		(9.82)	(18.42)	(2.31)

Table 2: Mean inflation in final three periods of each phase, by treatment

In Phase 1, we fail to reject H1 that inflation converged to the steady state target in *Baseline*, *HigherTarget* and *NegativeIR*. Inflation was significantly lower than the 10% target in *NegativeIR+Portfolio*.

We hypothesized in H2 that large deleveraging shocks would cause inflation to stabilize at the secular stagnation equilibrium. We cannot reject that inflation converged to the deflationary steady state of -18.3% in *HigherTarget*, *NegativeIR* and *NegativeIR+Portfolio*. Inflation also fell substantially in *Baseline*, but had not yet converged to the steady state predicted inflation rate of -24.3%.

We reject H3 that raising the inflation target to 30% would move the economy to the targeted equilibrium. Inflation in *HigherTarget* converged to -9.73% on average, with some sessions nearing zero inflation and others experiencing very negative inflation, which was significantly below 30%.

We predicted in H4 that removing the ZLB would restore inflation rate to the targeted equilibrium of 10%. We fail to reject H4 in *NegativeIR*, where the inflation rate average 8.59%. In *NegativeIR+Portfolio*, we find inflation modestly exceeds the target at 12%.

Finally, in H5, we hypothesized that introducing a portfolio choice would mute the stimulative effects of negative interest rates. We find the opposite. Inflation is significantly higher in Phase 3 when participants have a portfolio choice ($p = 0.0476$).

5 Unconventional Monetary Policy and Expectations

Critical to the success of inflation targeting policies is the management of inflation expectations. In this section we characterize how participants form their expectations in stable periods, and whether the deleveraging and policy interventions influence their nowcasting and forecasting heuristics. We consider seven different general forecasting models employed in the macroeconomic and finance literatures. Table 3 describes how both nowcasts and forecasts would be formed under each heuristic.

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 assumption that inflation today will equal the central bank's inflation target. The share of participants exhibiting M1 expectations can also be interpreted as the degree of central bank credibility. 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 stagna-

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 3: Nowcasting and forecasting heuristics

tion 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. 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. The distribution of types are presented, by phase, in Figures Figure 7 and Figure 8.

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.

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 notably in all treatments. This decrease in M1 Target heuristic is rational as the target is no longer

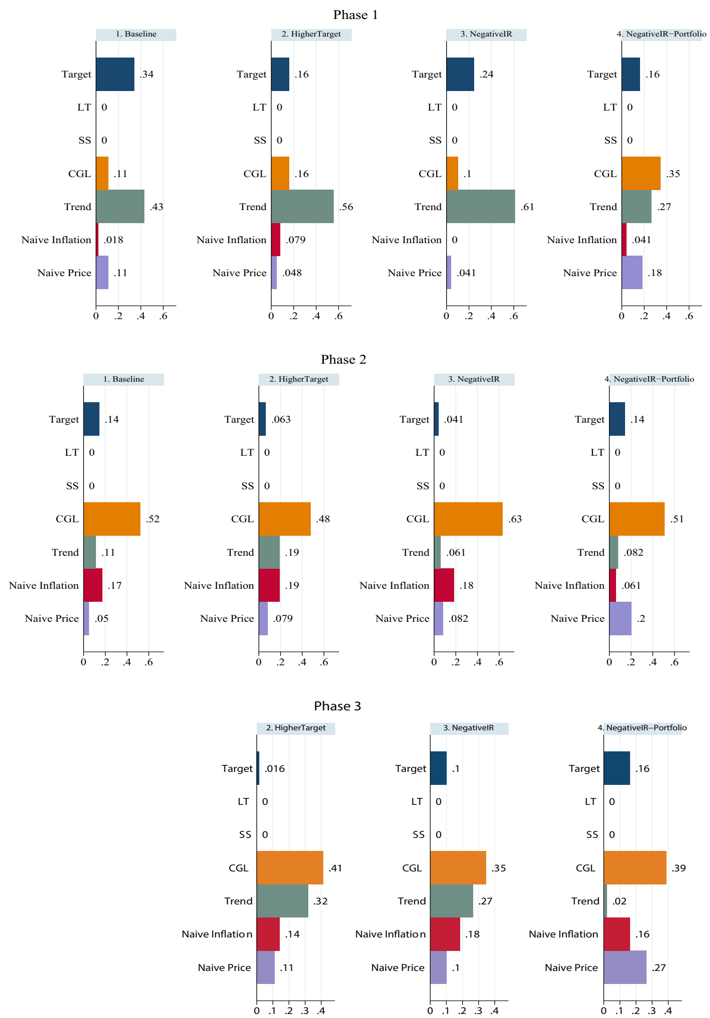


Figure 7: Distributions of nowcasting heuristics, Period t inflation, by phase and treatment

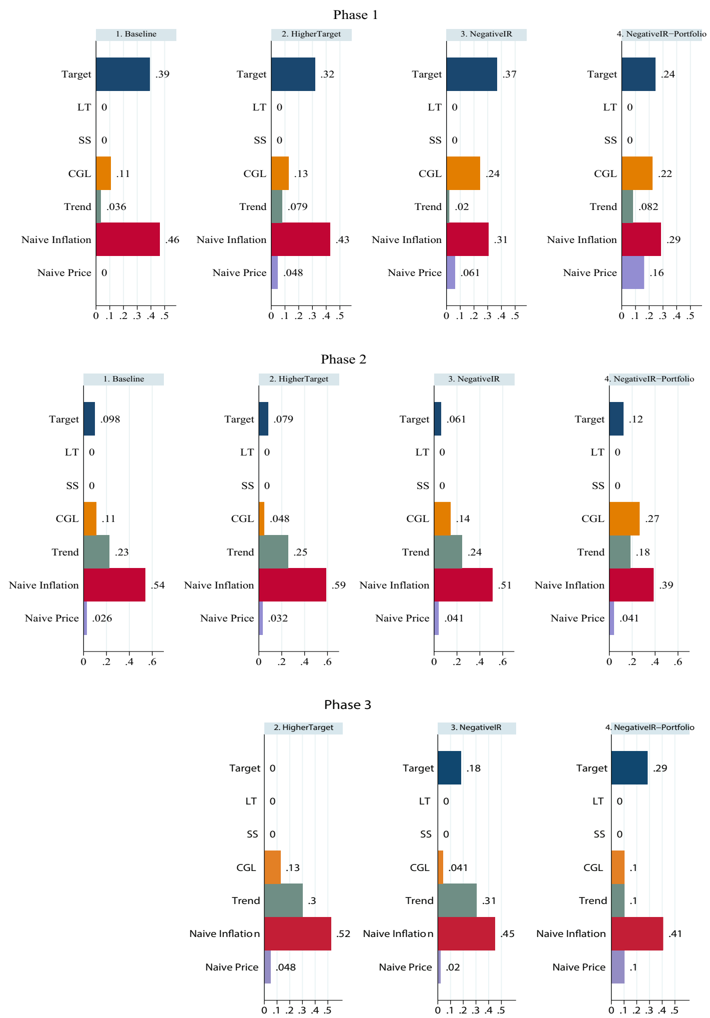


Figure 8: Distribution of forecasting heuristics, Period $t+1$ inflation, by phase and treatment

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. We also observe 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.

6 Monetary policy and consumption

We next explore how consumption, welfare, and inequality respond to permanent aggregate demand shocks and subsequent policy interventions.

Do people behave according to the Euler equation?

We start by evaluating how inflation expectations and monetary policy influence participants' intertemporal optimization. To do this, we estimate the following demand equation, motivated by the Euler equation:

$$CS^m_{i,t} = \alpha + \beta_1 E_t i_t + \beta_2 E_{i,t}\pi_{t+1} + \beta_3 E^{median}_t \pi_{t+1} + \beta_4 CS^m_{i,t-1} + \beta_5 CS^m_{i,t-2} + \mu_i + \epsilon_{i,t} \quad (14)$$

where $CS^m_{i,t}$, our outcome of interest, denotes the share of net income in period t used for current consumption. $E_t i_t$ is the market nowcast of the nominal interest rate, $E_{i,t}\pi_{t+1}$ is subject i's inflation forecast for period $t+1$ (which were formed in Stage 1 of each period), μ_i is a time-invariant subject fixed effect, and $\epsilon_{i,t}$ is the error term. Importantly, $E_t i_t$ is common knowledge and available to all participants when making their consumption decisions. We additionally control for market forecasts of period $t+1$ inflation, $E^{median}_t \pi_{t+1}$ which may alternatively shape participants' consumption decisions. We also include two lags of the dependent variable to control for persistence in consumption decisions. We estimate Equation (14) for each phase of each treatment to evaluate the evolution of aggregate demand in response to the permanent deleveraging shock and the policy interventions. We report results for *HigherTarget*, *NegIR*, and *NegIR+Portfolio* in Table 4.

We find that expectations play an important role in shaping aggregate demand and that the relationship between consumption and inflation expectations is theory-consistent. Our result demonstrate a strong relationship between inflation expectations and consumption both at and away from the ZLB. The effect is more pronounced for median inflation expectations, which we announce to all participants at the beginning of Stage 2 of each decision period. There is a strong social component to inflation expectations in that participants place greater weight on aggregate expectations than their own. This is especially the case in Phase 1 when participants are still learn-

Table 4: ConsumptionDemand

Dep.Var.	HigherTarget			NegIR			NegIR+Portolio		
$CS^m_{i,t}$	Phase 1	Phase 2	Phase 3	Phase 1	Phase 2	Phase 3	Phase 1	Phase 2	Phase 3
$\mathbb{E}_t i_t$	-0.340***	-1.310***	0.000	-0.183***	-0.665**	-0.553***	-0.637***	0.153	-0.203**
	(0.10)	(0.30)	(.)	(0.06)	(0.27)	(0.08)	(0.12)	(0.84)	(0.09)
$E_{i,t}\pi_{t+1}$	-0.199	0.068**	-0.002*	-0.000***	0.051***	0.123**	0.007	0.006	0.039***
	(0.13)	(0.03)	(0.00)	(0.00)	(0.00)	(0.06)	(0.01)	(0.01)	(0.01)
$E^{median}_t\pi_{t+1}$	0.751***	0.387***	0.197***	0.342*	0.363***	0.207*	0.965***	0.349***	0.521***
	(0.10)	(0.10)	(0.05)	(0.19)	(0.10)	(0.11)	(0.22)	(0.12)	(0.17)
$CS^m_{i,t-1}$	-0.605***	-0.325***	-0.236***	-0.662***	-0.516***	-0.281***	-0.418***	-0.153***	-0.293***
	(0.06)	(0.07)	(0.05)	(0.09)	(0.09)	(0.06)	(0.06)	(0.05)	(0.07)
$CS^m_{i,t-2}$	0.071	0.530***	0.527***	0.124	0.382***	0.444***	0.343***	0.529***	0.403***
	(0.06)	(0.04)	(0.10)	(0.14)	(0.10)	(0.05)	(0.06)	(0.05)	(0.07)
α	74.491***	34.682***	29.464***	75.217***	48.711***	32.393***	47.798***	24.484***	36.808***
	(3.99)	(4.40)	(5.01)	(11.11)	(8.58)	(4.53)	(4.14)	(3.44)	(6.26)
N	632	684	1027	630	684	1024	624	731	976
F	94.45	93.57	18.83	152.2	192.2	75.08	31.52	35.87	76.40

This table presents fixed-effects panel regressions evaluating how consumption responds to deleveraging shocks and policy interventions. Robust standard errors in parentheses. * $p < .10$, ** $p < .05$, *** $p < .01$

ing about the economy and the economy is relatively stable. As the deleveraging shock generates instability and inflation begins to decline, participants place less weight on the median expectation and more weight on their individual inflation expectation when making their consumption decision. Broadly speaking, inflation expectations play less of a role in shaping consumption decisions in the recession and following policy interventions.

A possible implication is that real-world economic instability that leads to the de-anchoring of expectations could also weaken the link between expectations and decisions. Indeed, as the economy stabilizes with negative interest rate interventions, the link between individual inflation expectations and consumption demand strengthens.

Monetary policy also influences consumption demand in a theory-consistent manner in all treatments. Higher aggregate nowcasts of the nominal interest rate lead to significantly lower individual demand and encourages greater saving. In Phase 3 of Higher Target, there are no sessions that experience above zero inflation and so the variable $E_t i_t$ is dropped from the specification.

The evidence for the relationship between inflation expectations and spending decisions is mixed. D'Acunto et al. (2016) and D'Acunto et al. (2018) find a theory-consistent relationship between inflation expectations and readiness to spend, Bachmann et al. (2015) finds that expected inflation decreases readiness to spend at the ZLB but not away from it while Binder and Brunet (2022) find no significant relationship between expected inflation and spending. Burke and Ozdagli (2021) find a positive relationship but only for households with at least some college education, which aligns with D'Acunto et al. (2019) who find an effect only for high-IQ survey respondents. In our experiment, participants have access to a consumption calculator to help them make optimal consumption decisions given their inflation expectations. In this sense, our subject face significantly less cognitive challenge. Our results, then, align with this literature suggesting that high cognitive ability individuals behave in a theory-consistent manner (D'Acunto et al., 2019; Burke and Ozdagli, 2021).

Consumption demand and negative interest rates

When nominal interest rates are allowed to become negative, participants may become more aware of the losses associated with saving. Loss aversion is a well-documented behavior where individuals prefer avoiding losses to acquiring equivalent gains (Tversky and Kahneman, 1991). In the context of our experiment, loss aversion may result in participants avoiding losses in their utility by consuming more for a one-unit decrease in the nominal interest rate when nominal interest rates are negative than when they are positive. In the *NegativeIR+Portfolio* treatment, participants may also circumvent the loss of saving from negative interest rates by holding their saving in cash rather than bonds. We next zoom in on spending decisions made in Phase 3 of *NegativeIR+Portfolio* where roughly 80% of periods had a negative expected nominal interest rate.[5]

We first document some results about portfolio choices. A probit regression (available upon request) shows that the average participant chooses between cash and bonds in a sensible manner. As nominal interest rates increase, the probability of a subject being invested in bonds increases significantly. When the nominal interest rate becomes negative, the probability of being invested in bonds increases substantially, and even more so as the rate becomes more negative. However, we do observe significant heterogeneity and persistence in participants' portfolio decisions. 16% of participants never adjust their portfolio composition in Phase 3, with an equal number of subjects holding only cash or bonds. We also observe a significant share of participants make irrational portfolio decisions. 28% of participants choose to hold bonds when nominal interest rates are expected to be negative. This share is relatively stable (ranging between one fifth and one third of participants in Phase 3) and indicative of a combination of inattentiveness and habit-persistence.

[5]In *NegativeIR*, nominal (real) rates were expected to be negative in 97% (98%) of periods and were actually negative in 93.2% (98%). This leaves us with relatively few observations to identify differential reactions of demand to negative rates.

Another 20% of participants remain invested in cash when nominal rates are expected to be positive, an irrational investment strategy we attribute additionally to excess skepticism or uncertainty about the expected policy rates presented on their screen.

To evaluate how consumption demand responds to negative policy rates, we extend our estimation equation Equation (14) as follows:

$$CS_{i,t}^m = \alpha + \beta_1 E_t i_t + \gamma_1 \mathbb{I}_{E_t i_t < 0} + \gamma_2 \mathbb{I}_{E_t i_t < 0} \times E_t i_t + \gamma_3 \mathbb{I}_{Bonds}$$

$$+ \beta_2 E_{i,t}\pi_{t+1} + \beta_3 E_t^{median}\pi_{t+1} + \beta_4 CS_{i,t-1}^m + \beta_5 CS_{i,t-2}^m + \mu_i + \epsilon_{i,t} \quad (15)$$

where $\mathbb{I}_{E_t i_t < 0}$ is a dummy variable that takes the value of one when the current nominal interest rate is expected to be negative, while $\mathbb{I}_{Bonds_{i,t}}$ is a dummy variable that takes the value of one if participant i chose to hold their saving in bonds. We estimate this equation first over the entire Phase 3 sample and then separately by participants' portfolio decision. The results are presented in Table Table 5.

Table 5: Consumption Demand

Dep.Var.	**NegIR+Portolio - Phase 3**		
$CS_{i,t}^m$	Full sample	Cash	Bonds
$\mathbb{E}_t i_t$	-0.485***	-0.121	-0.476**
	(0.19)	(0.60)	(0.22)
$E_{i,t}\pi_{t+1}$	0.041**	0.032*	0.203**
	(0.02)	(0.02)	(0.09)
$E_t^{median}\pi_{t+1}$	0.470***	0.439***	0.480**
	(0.13)	(0.16)	(0.24)
$I_{E_t i_t < 0}$	4.094*	1.701	4.825
	(2.32)	(4.76)	(3.49)
$\mathbb{I}_{E_t i_t < 0} \times \mathbb{E}_t i_t$	0.533***	0.067	0.824***
	(0.19)	(0.60)	(0.24)
$CS_{i,t-1}^m$	-0.306***	-0.275***	-0.485***
	(0.03)	(0.04)	(0.05)
$CS_{i,t-2}^m$	0.386***	0.416***	0.244***
	(0.03)	(0.03)	(0.05)
I_{Bonds}	-0.379		
	(1.57)		
α	38.626***	36.772***	53.923***
	(3.40)	(5.66)	(5.73)
N	976	605	371
F	77.63	48.15	43.15

This table presents fixed-effects panel regressions evaluating how consumption responds to deleveraging shocks and policy interventions. Robust standard errors in parentheses. * $p < .10$, ** $p < .05$, *** $p < .01$

We begin with the entire sample of *NegativeIR+Portfolio* participants in Phase 3. When nominal interest rates are positive, a higher nominal interest rates has a large negative and statistically significant effect on consumption demand. When nominal interest rates are negative, irrespective of the level of the policy rate, aggregate demand increases by 4.09 percentage points. The effect of the nominal interest rate on demand is completely eliminated when participants expect nominal interest rates to be negative. In fact, as rates become highly negative, demand contracts.

For those participants who hold their saving in cash, the nominal interest rate is statistically and quantitatively irrelevant in their spending decision. The opposite is true for those who are saving in bonds. Bond holders spend spending out of net income by roughly 4.8 percentage points on average. As rates become more negative, bond holders also cut back their spending significantly, suggesting participants are responding to a strong negative income effect. A one-percentage point decrease in the nominal interest rate when rates are expected to be negative negative leads to an average 1.3 percentage point (-0.476(-1) + 0.824(-1)) decrease in the share of net income used for current consumption.

Are bond holders faring worse when rates are negative? Yes. Average points from utility earned from current middle-aged and the next period's old-aged consumption is 7.36 for cash holders and 7.22 for bond holders (a two sided t-test that the means are identical yields a p-value of 0.0883, N=931). Bond holders choose to spend relatively more on current consumption and less on future consumption, thereby avoiding some of the effects from negative interest rates.

Consumption Heterogeneity

We also observe considerable consumption heterogeneity in all treatments despite providing common information about market-expected rates and inflation alongside an expectations-based consumption calculator before subjects made consumption-saving decisions. To better understand this heterogeneity, we estimate the following model:

$$SD(c_{i,t}) = \alpha + \beta_1 \mathbb{I}Phase2 + \beta_2 \mathbb{I}Phase3 + \mu_i + \epsilon_{i,t} \quad (16)$$

where $SD(c_t^m)$ is the standard deviation of real consumption at the session-period level, $\mathbb{I}Phase2$ and $\mathbb{I}Phase3$ are indicators for treatment phase, and α is a constant that captures the baseline level of consumption heterogeneity. Here, $\mathbb{I}Phase2$ captures the change in consumption heterogeneity that occurs after our economies experience a deleveraging shock and $\mathbb{I}Phase3$ how it changes after the central bank intervenes. We present estimation results for treatments with policy interventions by treatment (columns 1 through 3) in Table 6 where *HT*≡*HighterTarget*, *NegIR*≡*NegativeIR*, and +*Portfolio*≡*NegativeIR*+*Portfolio*. Note that real consumption in our model is isomorphic to consumption utility. Because of this, we consider our measure of consumption heterogeneity a measure of inequality and refer to the two interchangeably throughout this section.

	HT SD$_t(c_{i,t})$	*NegIR* SD$_t(c_{i,t})$	+*Portfolio* SD$_t(c_{i,t})$	*HT* AW	*HT* AW	*NegIR* AW	*NegIR* AW	+*Portfolio* AW	+*Portfolio* AW
Phase2	0.031**	0.050**	0.062***						
	(0.012)	(0.015)	(0.010)						
Phase3	0.059**	0.062***	0.041**						
	(0.024)	(0.013)	(0.013)						
SD$_t(C_{i,t})$				-89.658***	-41.655***	-37.077**	-26.807***	-97.077***	-44.585***
				(19.319)	(10.320)	(13.401)	(5.657)	(17.435)	(4.724)
Y$_t$					5.648***		4.622**		8.627***
					(1.374)		(1.634)		(0.540)
α	0.063***	0.053***	0.130***	59.530***	19.176*	56.403***	24.081*	63.821***	-0.937
	(0.013)	(0.009)	(0.006)	(1.876)	(9.199)	(1.264)	(10.713)	(2.886)	(3.072)
N	343	343	343	343	343	343	343	343	343
r$^2_{within}$	0.265	0.433	0.233	0.452	0.799	0.249	0.606	0.297	0.891
r$^2_{adjusted}$	0.261	0.430	0.228	0.451	0.798	0.246	0.603	0.295	0.890

Table 6: This table reports results from a series of fixed effects regressions. The first three columns provide estimates of how consumption heterogeneity at the session-period level [$SD_t(C_{i,t})$] changes after experimental economies experience a deleveraging shock (Phase2) and after the central bank intervenes (Phase3). The last six columns estimate how aggregate welfare at the session-period level (AW) responds to this consumption heterogeneity. Note that we present these results with and without controlling for the corresponding level of output (Y_t). Note *HT*≡*HighterTarget*, *NegIR*≡*NegativeIR*, and +*Portfolio*≡*NegativeIR*+*Portfolio*. Robust standard errors reported in parentheses. * $p < .10$, ** $p < .05$, *** $p < .01$

Several features of inequality are worth noting. First, introducing a portfolio choice into our experimental framework significantly increases consumption heterogeneity, which is likely due to the increased complexity of decision making. To see this, note that $alpha$ is at least twice as large in +*Portfolio* as it is in either *HT* or *NegIR*. Second, deleveraging shocks significantly increase consumption heterogeneity. Relative to Phase 1, consumption heterogeneity in Phase 2 increases by about 50% in *HigherTarget*, almost 100% in *NegativeIR*, and almost 50% in *NegativeIR-Portfolio*. Third, this increase in consumption heterogeneity persists into Phase 3. this is true even for *NegIR* and +*Portfolio* where the policy intervention consistently yields economic recovery. Though negative interest rates effectively restore output and employment while aligning inflation with the nominal target, they cannot reduce inequality to pre-shock levels. However, negative rates that consistently close the output gap can mitigate the inequality that arises in our experimental economies following deleveraging shocks.

What are the welfare implications of this inequality? To answer this, we estimate

$$AW = \alpha + \beta_1 SD(c_{i,t}) + \beta_2 Y_t + \mu_i + \epsilon_{i,t} \tag{17}$$

where AW is aggregate welfare measured at the session-period level by summing consumption utility of all subjects in a session, $SD(c_{i,t})$ is the same as in Equation (16), and Y_t is real output at the session-period level. We control for output in this model because a decline output will mechanically yield a fall in aggregate welfare and because it is more likely to observe consumption heterogeneity in periods where we also observe an output gap. Note that including this controls significantly improves the fit of our model. We report results from estimating Equation (17) in columns 4 through 9 of Table 6.

The main result in Table 6 is that the inequality that results from deleveraging shocks significantly decreases aggregate welfare, even after controlling for the corresponding shortfall in output. This means that demonstrably costly inequality persists even when negative interest rates can successfully restore an economy to full output, full employment, and to the inflation target. This begs the question whether policy could or should do more to address heterogeneity even when aggregation sufficiently balances heterogeneity to restore an economy to its steady state equilibrium path.

7 Why do negative rates work but higher targets fail?

This section explores why negative interest rate policies are more effective than inflation targeting policies in our experimental economies. To aid in this discussion, we include Figure 10, which focuses on treatment-level effects of policy interventions for the five periods before and ten periods after the policy intervention.

We begin 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 be-

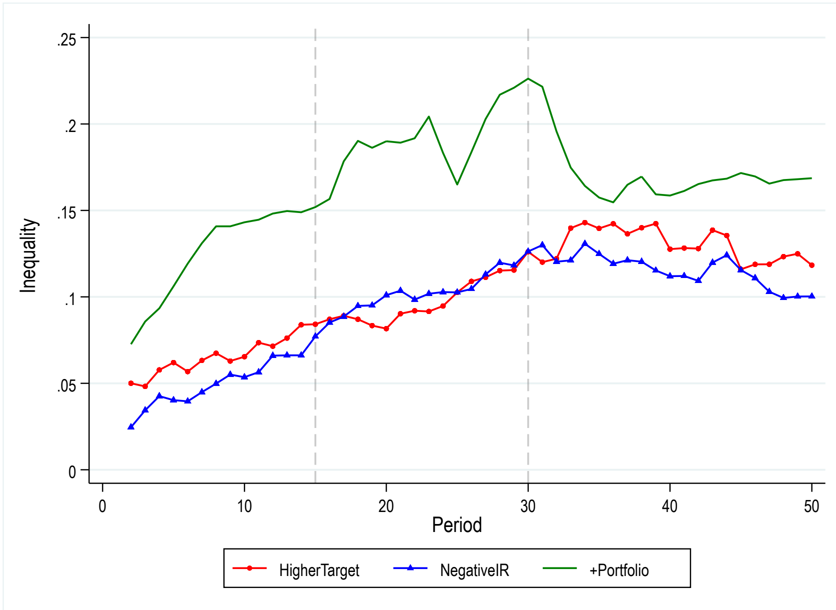


Figure 9: This figure depicts inequality over time by treatment. Treatment-level inequality is measured in each period as the mean of session-level standard deviations of real consumption. Note we consider this a measure of inequality because real consumption and utility are isomorphic.

cause agents do not necessarily expect the ZLB to become non-binding in the future. A breakdown of any of these three necessary conditions (forward-looking expectations, coordinating expectations on the higher target, or expectations-consistent real decisions) will prevent economies from converging to the full-employment equilibrium. A breakdown of any of these three necessary conditions (forward-looking expectations, coordinating expectations on the higher target, or expectations-consistent real decisions) will prevent economies from converging to the full-employment equilibrium.

Do subjects make real decisions consistent with their expectations? Yes. We show this in Online Figure 19a, 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.

The intervention in *HigherTarget* fails to coordinate nowcasts or forecasts on the central bank's new target. Subjects in our experiment overwhelmingly employ backward-looking forecasting heuristics (see Figure 7). The majority of subjects in *HigherTarget* form expectations using trend extrapolation in Phase 1, and constant gains learning in Phases 2 and 3. Subjects base their ex-

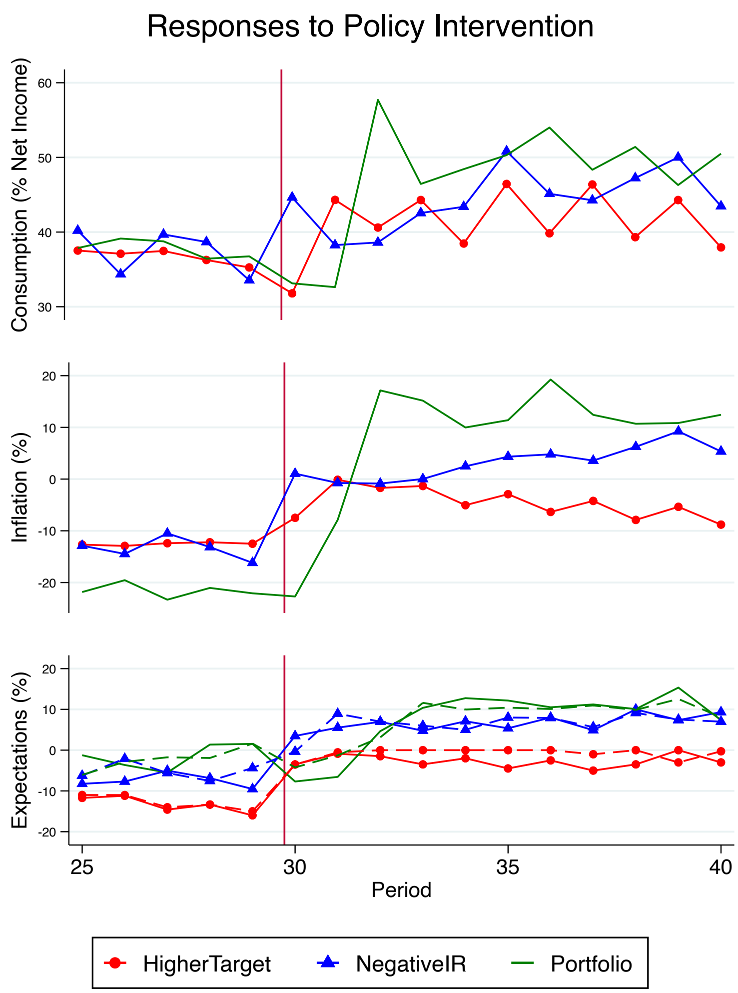


Figure 10: Aggregate dynamics around the policy intervention

pectations largely on the recessionary conditions at the end of Phase 2 – rather than on the new inflation target – when transitioning into Phase 3. The intervention's underwhelming effect on impact 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 10).

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 results in below-target inflation, a negative output gap, and depressed wages.

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.

Subjects in *NegativeIR* and *NegativeIR+Portfolio* also make real decisions that are consistent with their inflation expectations (see Online Figure 19b). Moreover, consumption decisions respond in a way that is qualitatively consistent with prevailing rates in our negative rates treatments. In both *NegativeIR* and *NegativeIR+Portfolio*, mean consumer spending increases by more than 80% on impact of the interventions.

Inflation expectations react to the introduction of negative interest rates. This is visible in the expectations panel of Figure 10, where both treatment-level nowcasts and forecasts increase in the period immediately following the announcement of the new policy change. As 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.

We conduct a series of Granger causality tests using session-level aggregate results 5-periods before and 5-periods after the intervention and evaluate the direction of causality in consumption and expectations. We observe that 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*, where inflation expectations Granger cause consumption. That is, the intervention in *HigherTarget* fails because expectations under-react to the new target as participants do not perceive it as credible.

Negative rates remain effective in *NegativeIR+Portfolio* despite some subjects continually holding cash. This is because enough subjects continue holding bonds such that aggregate dynamics shift in a theory-consistent way in response to the introduction of negative rates. This leads to inflation, higher inflation expectations, higher wages and higher output following intervention. Consequently, subjects holding cash in later periods face similar erosive effects on their real wealth due to 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.

8 Conclusion

This paper introduces a new experimental framework to study secular stagnation and the ability of unconventional policies to alleviate potentially permanent output gaps. Our experimental economies evolve endogenously according to subjects' price forecasts and budgetary decisions. We engineer secular stagnation by imposing exogenous and permanent deleveraging shocks. We then allow the central bank to address these persistent recessions by either permanently increasing its inflation target or implementing negative policy rates.

Raising inflation targets has limited ability to stimulate inflation expectations and alleviate secular stagnation after a sufficiently lengthy episode of deflation. The central bank's credibility in achieving a higher target is limited when it struggles to achieve its original target. 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.

Our findings in *HigherTarget* are consistent with the observed response of inflation in Japan following the BoJ's attempt in January 2013 to address persistent deflation by doubling its own inflation target from 1 to 2% (see **?**). 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 also suggest that weak existing credibility at the ZLB can limit the potency of higher targets. weak credibility may have contributed to the inability to stimulate inflation

Negative rates, by contrast, facilitate rapid economic recovery. This is because subjects' spending increases immediately at the prospect of negative interest rates. The immediate inflation leads backward-looking subjects to form more inflationary expectations and greater spending in subsequent periods. Introducing a portfolio choice does not mute the effectiveness of negative interest rates. Rather than hoard cash, a majority of subjects in our experimental economies continue to hold bonds and incorporate negative rates into their real decisions. Their rapid increase in consumption and inflationary expectations work in tandem to pull 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 reluctance of commercial banks to impose negative deposit rates on households. This imposition of a ZLB on household deposit rates dampened the intertemporal transmission channel. 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.

Learning-to-forecast experiments that study expectation formation at the ZLB have demonstrated how difficult it is to reverse pessimistic expectations when monetary policy is inactive (Arifovic and Petersen, 2017; Hommes et al., 2019; Mauersberger, 2021; Kostyshyna et al., 2022). In LtFEs, the evolution of an economy is driven largely by participants' aggregate expectations (and, to a lesser extent, exogenous shocks). As inflation expectations decline and become ever-unanchored, economic activity and deflation worsen mechanically. An open question in this literature is whether forecasters would act on their expectations, especially when that would mean reducing their consumption (and, thus, welfare) significantly. Our results show that there exists a significant positive relationship between expectations and consumption decisions, and that participants significantly reduce their spending if they anticipate deflation in the future.

We also demonstrate how a complex general equilibrium theoretical framework can be distilled to a simple implementation that nonetheless allows for a meaningful interaction of expectations, decisions, and monetary policy. By bridging learning-to-forecast and production economy experiments, our framework produces individually-linked expectations and consumption data. This rich data source allows important insight about the relationship between expectations and real decisions that complement an existing empirical literature (Coibion et al., 2020b,a, 2019; D'Acunto et al., 2016). To discern why inflation targeting can fail, it is important to understand whether the problem is that people do not form expectations consistent with the policy objectives of the central bank or that they do not form expectations-consistent decisions. This flexible framework can be easily extended to allow for fiscal policy, credit markets, policy communication and coordination.

Overall, 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 through the expectations channel.

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A Automation of Young and Old Agents

We automate the behavior of young households to align with EMR's theory. We also automate the decisions of old households in that our software automatically spends everything assigned to that household in the previous period by one of our student subjects. 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.[6] 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.[7]

B Instructions

We provide a copy of our experimental instructions in this section. To save space, we include the common component of the instructions and then denote throughout whenever things differed between treatments.

EXPERIMENTAL STUDY OF ECONOMIC DECISION MAKING

Welcome! You are here today to participate in an economic experiment involving the experimental simulation of an economy. If you read these instructions carefully and make appropriate decisions, you may earn a considerable amount of money that will be paid to you in cash immediately following the experiment.

We will pay each participant $10 for attending this experimental session. Throughout the experiment you will also earn points based on the decisions and predictions you make. Every 20 points you earn is worth $1.

During the experiment you are not allowed to communicate with other participants. If you have any questions, the experimenter will be glad to answer them privately. If you have not done so already, please turn off your cell phone now. If you do not comply with these instructions, you will be excluded from the experiment and deprived of all payments aside from the minimum payment of $10 for attending.

Your task is to make predictions and budgeting decisions for computerized households that interact in an experimental economy. These instructions will explain how you will make forecasts and budgeting decisions, and your actions will translate into points and payments for you.

[6] 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.

[7] 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.

Overview:

In this experiment, you will make budgeting decisions for assigned households. These households live for three periods. We describe them as **Young** in the first period of life, **Middle-Aged** in the second period of life, and **Old** in the third period of life. You will be responsible for making budgeting decisions for an assigned household in the Middle-Aged and Old periods of its life. A computer automates decisions for Young households. At any point in time, there will be 7 Young, 7 Middle-Aged, and 7 Old households, for a total of 21 households.
Households in this economy purchase a single good called **output**. You will do two things in each period of this experiment.

1. You will **predict** the unit price of output for the current period and the next period.
2. You will decide how your assigned household should **split its spending** between Middle-Aged and Old periods of its life.
3. *You will decide how much of your savings you want to hold as cash (earns no interest) and bonds (earns interest). We call this your portfolio decision.*

Note that the third item was included only in the NegativeIR+Portfolio sessions

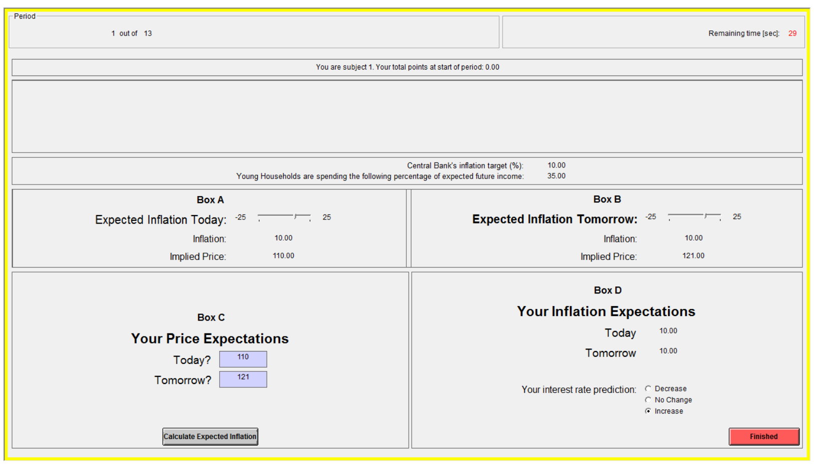
You will earn points based on the accuracy of your output price forecasts. The more accurate your forecast, the more points you earn. You also earn points when your assigned household purchases output. The more your assigned household buys, the more points you earn. Throughout the game, you will receive historical information about your personal decisions and the points you have earned. You will also receive information about the overall economy. Since we will refer to these different pieces of information in the instructions, we will give you simple definitions below. **Output Produced** - The total amount of production in the economy. **Price** - The price for one unit of output. **Inflation** - The percentage change in the price between the last period and the current period. Inflation can be **negative, zero, or positive**. Negative inflation means prices are falling; positive inflation means prices are rising; zero inflation means prices remain constant. **Inflation Target** - The level of inflation the central bank is aiming to achieve over a number of periods. Interest Rate - The rate at which your savings will grow between two periods. This interest rate is determined by the central bank. **Income** - The amount of lab money you can split between spending and saving when Middle Aged. ***Portfolio:*** *The mix of cash and bonds* *that you use to make up your savings. Note the definition for Portfolio was only included in the NegativeIR+Portfolio sessions*

Period

Each period will consist of two stages: a forecasting stage and a budgeting decision stage.

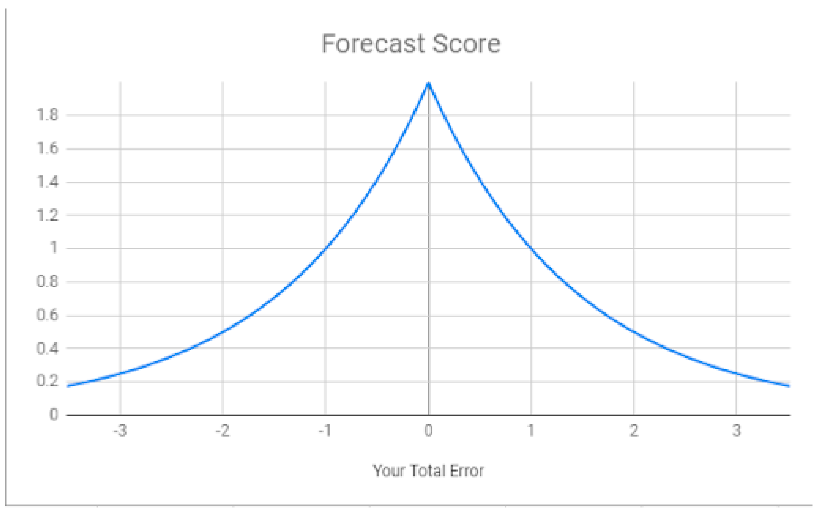
Stage 1 - Price/Inflation Forecasts

Each period will involve you making two price forecasts. You will make predictions about the current and next period's output prices. You will earn points based on the accuracy of your forecasts. We provide you with two tools that assist you in making the connection between prices and inflation. These are provided in Boxes A, B, C, and D. **<u>Tool 1: Boxes A and B</u>** Boxes A and B al-



low you to experiment with different levels of expected inflation for the current and next period to see what this would imply for the actual price level. Begin by sliding the marker in Box A to indicate by what percentage you expect prices to fall or rise in the current period. The **Implied Price** for the current period will update as you move this slider. After making your prediction in Box A, adjust the slider in Box B to see an Implied Price for tomorrow. Box B's implied price will depend on your prediction in Box A. Importantly, if you change your prediction in Box A, you must reset and update your prediction in Box B to receive the correct implied price in Box B. **<u>Tool 2: Boxes C and D</u>** Boxes C and D allow you to translate predicted prices into inflation expectations. Type in your forecasts of current and next period's prices in Box C. By clicking on the grey button "Calculate Expected Inflation", you will see in Box D what your implied inflation forecasts are. You can do this as many times as you'd like. The program records no information until you submit your final price forecasts. **Submitting Your Price/Inflation Forecasts:** To submit your forecasts, you must type your **final price forecasts into Box C** and click on the **red "Finished" button**. You will have 60 seconds to submit your price forecasts. You will earn zero points if you do not submit your forecasts on time. Notice that the sliders allow you to select an inflation forecast from -25% to +25%. However, your final price forecasts can always imply a price change outside of this range. **How You Earn Points For Your Price/Inflation Forecasts:** Once a price is calculated at the end of a period, the software will evaluate your forecast formed in the previous period about the current price and your forecast formed in the current period about the current price. Your forecasting score, at the end of a round, will be given by:

$$ForecastPoints_t = 2^{(2-|FuturePriceForecastError_t-1|+2-|CurrentPriceForecastError_t|)}$$

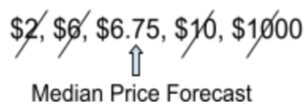


- A perfect forecast for each of these forecasts for a given time earns you 2 points
- Thus, A perfect forecast yesterday and today earns a total of 4 points
- Your score drops in one-half for each lab dollar your price forecast is incorrect
- You will never earn negative points for your forecasts

Submitting your Interest Rate Forecast Before clicking the "Finished" button, please indicate whether you think the interest rate in the current period will decrease, increase, or remain unchanged. For each correct guess, you will earn 2 points.

How do forecasts influence the economy?

The median (i.e. middle) price forecast for the current period collected from all subjects will be used to calculate expected income in the current and future periods and expected current interest rates. The expected current income and interest rate will be presented to all subjects when they make their budgeting decisions. The expected future income will determine how much the automated Young households can spend on output. Suppose we have 5 participants providing price forecasts. Then, the following is an example of how we select the median price forecast: Finally, the automated Young households will spend 35% of their expected future income.



Forecasts about the current interest rate change will have no impact on the economy.

Stage 2 - Individual Decisions:

In Stage 2 of each period, you will make a budgeting decision for an assigned Middle-Aged household. Your assigned Middle-Aged household is predicted to earn a certain level of income in the current period. You will decide what percentage of that predicted income your household should spend today. The unspent income will earn interest and be available to that household in the next period when the household becomes Old. Importantly, the Old household will automatically spend all of its remaining wealth on output and you will earn points for its purchase of output. The table below shows how decisions impact current and next period's outcomes. ***Portfolio:*** *You may hold savings as cash or as bonds. Cash does not earn interest whereas bonds do earn interest. Note that both cash and bonds are equally easy to spend in this experiment. Suppose you end the period with 100 lab dollars and that the interest rate is 10%. If you hold your savings as as bonds, then your household will have 100*(1+.1)=110 lab dollars for spending in the following period while old. If instead you hold cash, your household will have 100 lab dollars to spend in the following period. Suppose instead the interest rate is -10%. If you hold your savings as bonds, then your*

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 11: Co-determination of middle-aged and old spending

household with have 100(1+(-.1))=100*.9=90 lab dollars to spend in the following period. If instead you hold cash, your household will have 100 lab dollars to spend in the following period. The central bank uses interest rates to keep output and employment as high as possible without creating too much, or allowing for too little, inflation. Sometimes the central bank does this using positive interest rates. Sometimes the central bank does this using negative interest rates. In this experiment, the central bank uses interest rates to influence how each of you spends and saves money. Note that we only included these 3 paragraphs for the NegativeIR+Portfolio sessions* **Information:** You will receive forecasts about your current income, the current interest rate, the median subject's expected price for the current and next period, as well as information about how much young households will be borrowing from their future income. **Budgeting Tool:** You must decide how much of its **forecasted income** your middle-aged should spend today. We provide you with a calculator (pictured below in the middle box titled 'Optimal Spending Calculator') to help you make this budgeting decision. Begin by typing in predictions of the price level in the current and next periods. These price predictions may be the same as your previous price predictions, may be the median price prediction displayed here, or may be any other strictly positive number. Clicking the"Calculate Optimal Spending" button will cause the current period's predicted interest rate and the optimal level of spending to update. Note these values are conditional on your price expectations and will be different for different price expectations. By 'optimal level of spending' we mean the level of spending today that, conditional on your price expectations, will maximize your household's lifetime consumption. This implies that 'optimal level of spending' is the level of spending today that, conditional on your price expectations, will maximize the money you earn from your household. You can also experiment with different spending decisions. In the box "Lab Dollars for Spending Today", indicate how many dollars you would like to spend. By clicking "Calculate Predicted Points" you can see how many points you would hypothetically earn given your price forecasts and spending decisions. Note that all these values are hypothetical. The actual price levels, interest rate and optimal decisions will depend on the spending decisions of all households in the economy. **Submitting Your Spending Decisions:** To submit your spending

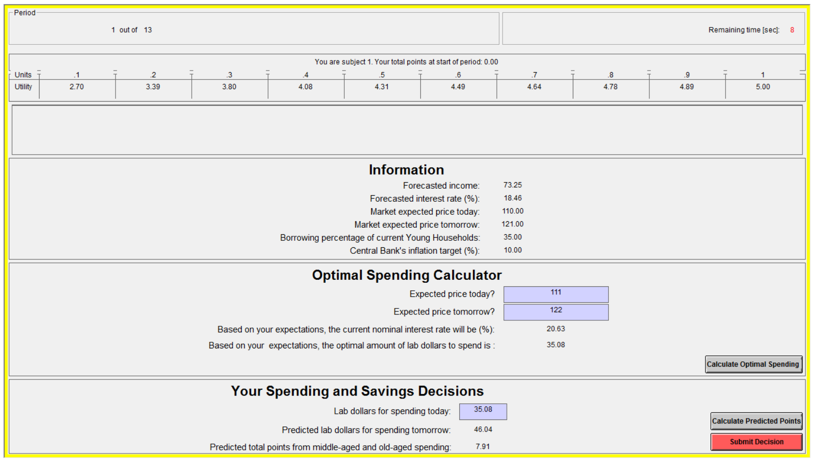


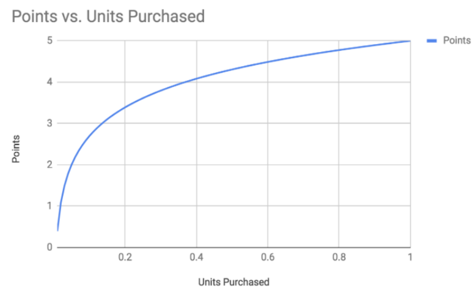
Figure 12: Co-determination of middle-aged and old spending

decision, you must input your budgeting decision as any number between 0 and your predicted income and click on the red "Submit Decision" button. You may use up to two decimal places for your entry. Please review your decision before clicking the Submit button. Once you have clicked it, you may not reverse your decision. **How You Earn Points for Your Spending Decisions** Each additional unit purchased by your household within a single period earns you a positive, but diminishing number of points. Specifically, the number of points you will earn for your purchases in a single period is given by: Points= 5+ ln(.0067 + units purchased)

- Spending more money in a single period will allow you to earn more points
- Each additional lab dollar you spend in a single period earn you less than the previous dollar
- The above table is a coarse grid of payoffs. In fact, you may purchase and consume fractions of a unit to two decimal places. E.g. Purchasing 0.35 units would earn you 3.97 points. It is possible to purchase and consume more than 1.0 unit.

To understand how this diminishing returns to consumption spending within a period works, we provide three examples.

Suppose you are assigned a Middle-Aged household in Period 1 whose income is 10 lab dollars. Further, assume that the price of output is 10 lab dollars and that the interest rate and inflation



Units Purchased	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
Points	0	2.7	3.39	3.8	4.08	4.31	4.49	4.64	4.78	4.89	5

Figure 13

rates are 0% (so your savings earn no interest and the price of output does not change in the following period).

1. If you instruct your household to spend all of its $10, then today it will purchase 1 unit of output ($10 income spent/$10 price per unit = 1 unit purchased) and tomorrow it will purchase nothing. This will earn you a total of 5 points in Period 1 and 0 points in Period 2.

2. Now assume that you instruct your household to spend $4 (40% of its income) today. It will purchase 0.4 units today ($4 income spent/ $10 price per unit= 0.4 units purchased), and have $6 in saving. If prices remain the same tomorrow, you will purchase 0.6 units tomorrow ($6 spent / $10 price per unit = 0.6 units purchased). This will earn you a total of 4.08 + 4.49=8.57 points.

3. Finally, suppose that you instruct your household to spend $2 (20% of its income) today. Then today your household will purchase 0.2 units and tomorrow it will purchase 0.8 units. This earns you a total of 3.39 + 4.78 =8.17 points.

The above are examples that are meant to clarify the diminishing benefits to consumption spending.

- You will frequently observe interest rates above zero. Higher interest rates mean more return on saving and, all else equal, more money for your Old household to spend.

- You will frequently see prices change. Your household will be able to purchase more units of output, and earn more points, when prices are lower.

Income, Prices, and Units

After all players specify how much their Middle-Aged households should spend, the software will compute the total amount of output that will be produced, the number of dollars to be spent on output in the current period and the market clearing price. Once the market clearing price is determined, the income of the Middle-Aged will be calculated. Middle-Aged income will be simply equal to the price of output.

The more (less) total dollars being spent on output, the more (less) output will be produced. The economy can produce a maximum of 7 units. These units will be divided among Young, Middle-Aged, and Old households. Households will be able to purchase fractions of a unit. Your household will receive more units of output if they have a larger amount of money to spend.

Monetary Policy A computerized **central bank** operates in the background. The central bank's objective is to keep prices growing at a constant rate. This constant rate is called their **inflation target**. The central bank will announce its inflation target at the beginning of each period. This will be shown in the upper-middle of your screen. Suppose the central bank's inflation target

Figure 14

is 10%. This means that if the price of a unit of output is 10 in the previous period, the central bank's targeted price for the current period is 10 x 1.10 = 11 and for the next period is 10 x 1.10 x 1.10 = 12.10 (equivalently, 11x1.10=12.10) Note that this is only a target for inflation. You may observe inflation levels that are negative, positive, or zero. To achieve its targeted inflation, the central bank will adjust their interest rate at the end of each period in response to changes in the current price of output. It will increase the nominal interest rate when inflation is above its target, and it will lower the nominal interest rate when inflation is below its target. More precisely, it will use the following rule to set its interest rate:

$$interestrate_t = max\{1,\ \psi \left(\frac{inflation_t}{inflation\, target}\right)^2\} - 1$$

Note that $\psi = 1.13$ *in our baseline sessions and* $\psi = 1.846$ *in all other sessions*

baseline session example

For example, suppose that inflation = 10 and the inflation target = 10. Then the central bank will set the interest rate at 1.13(10/10)2- 1=1.13*1 -1=1.13-1. In words, this is saying that if actual inflation is 10-percent when the central bank is targeting 10-percent then the central bank's interest rate will be 13%.

Example for all other sessions:

For example, suppose that inflation = 10 and the inflation target = 10. Then the central bank will set the interest rate at 1.1846(10/10)2- 1=1.1846*1 -1=1.1846-1. In words, this is saying that if actual inflation is 10-percent when the central bank is targeting 10-percent then the central bank's interest rate will be 18.46

Note that the central bank will increase (decrease) the interest rate more than one-for-one with increases (decreases) in inflation relative to its target. For example, if inflation rises from 10% to 15%, then the central bank will increase the nominal interest rate by more than 5% in an effort to return inflation to its 10% target.

Importantly, if inflation falls too low, the nominal interest rate will decrease to zero and not decline any further.

Stage 3 - Review Screen

After you have made your budgeting decision, you will receive information about what happened in the current period to your currently assigned Middle-Aged household and your currently assigned Old household. Note that the the outcomes of the assigned Old household depended, in part, on your budgeting decision for your assigned Middle-Aged household **in the previous period**.

You will also receive information about the price of output, inflation in prices, the central bank's interest rate, and the total production in the economy.

In the next period, the following will occur:

1. You will make a new set of forecasts for the current and subsequent period.

Summary of Period

Your Points

Middle-Aged consumption units:	0.32
Middle-Aged consumption points:	3.88
Old consumption units:	0.35
Old consumption points:	0.00
Forecasting points:	3.26

Economic Information

Unit price this period:	109.33
Inflation this period:	9.33
Interest rate this period:	17.02
Output this period:	1.00

2. You will be assigned a new Middle-Aged household whose budget you will set.
3. Your previous period's Middle-Aged household will now become an Old household and will automatically buy goods with the budget you previously allocated it. Importantly, the Old household will spend all of its remaining wealth on output.

You will repeat this game for many periods. After a household is Old, it dies and is replaced by a new Young household.

To help you keep track of your decisions over time, we provide you with a history box located at the top of all screens.

Period	Current Price Forecast	Future Price Forecast	Points Earned from Forecasts	Middle-Aged Units	Middle-Aged Points	Old Units	Old Points		Price	Inflation (%)	Inflation Target	Income	Interest Rate (%)	Output Produced
1	11.00	12.10	1.31	0.33	3.89	0.33	0.00		10.39	3.94	10.00	10.39	5.77	3.00

Payments

After the experiment and questionnaire, we will convert your total points into dollars and pay you immediately in cash.

In addition to these primary instructions, *NegativeIR* and *NegativeIR+Portfolio* including a second handout that we provided to subjects between periods 30 and 31 whenever we announced the central bank's intention to begin using negative nominal rates.

Removing the Zero Lower Bound

The central bank will now allow interest rates to become negative if inflation falls sufficiently below its target.

Negative interest rates cause savings to shrink. For example, saving 10 lab dollars with a -10% interest rate would yield savings equal to 10(1+ (-.1))= 9 lab dollars.

On the other hand, negative interest rates imply that you will have less debt to repay when middle-aged household. For example, a young household that borrows 10 lab dollars will only owe 9 lab dollars once middle-aged. Thus, you have more disposable income to split between consumption and saving while middle-aged.

This change is permanent.

B.1 Session-Level Data with Individual Consumption and Expectations

HigherTarget

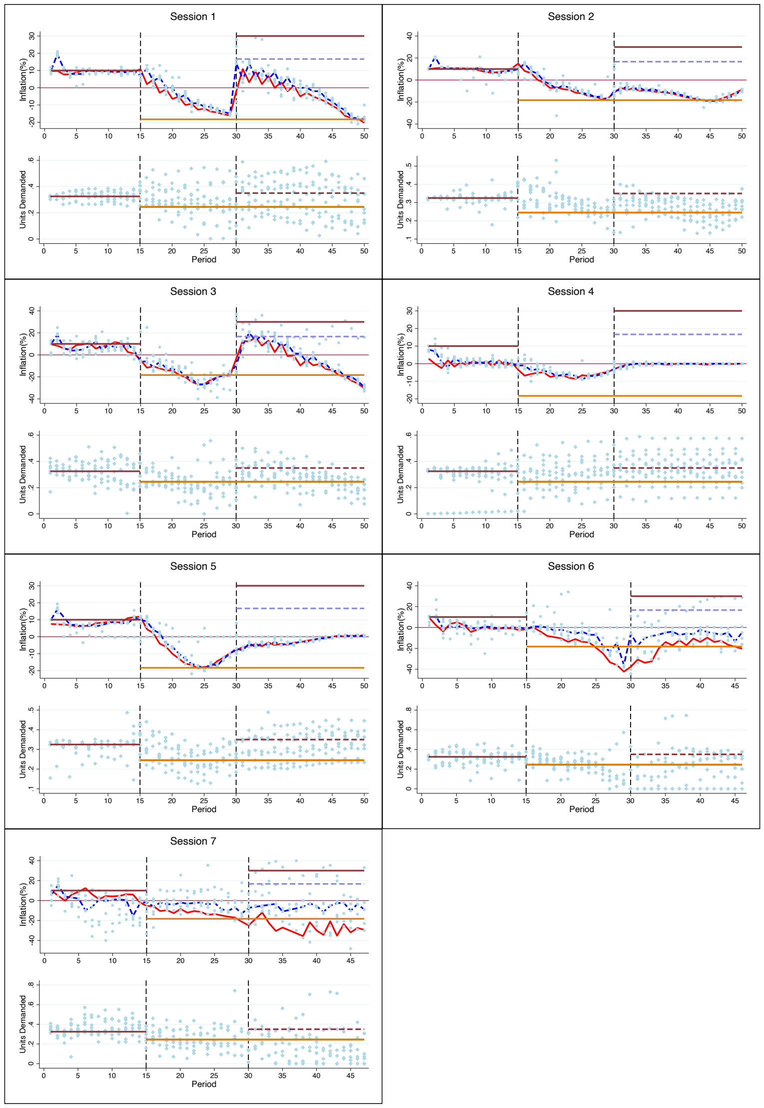


Figure 15: Individual-level inflation expectations (top, dots) and consumption (bottom, diamonds) data for *HigherTarget* sessions. Horizontal lines denote steady state levels of consumption and inflation. Maroon lines correspond to the central bank's inflation target, dark orange lines correspond the secular stagnation equilibrium, and dashed lines correspond to the liquidity trap equilibrium. Dashed time series line denotes median inflation expectation. Solid time series line denotes actual inflation.

NegativeIR

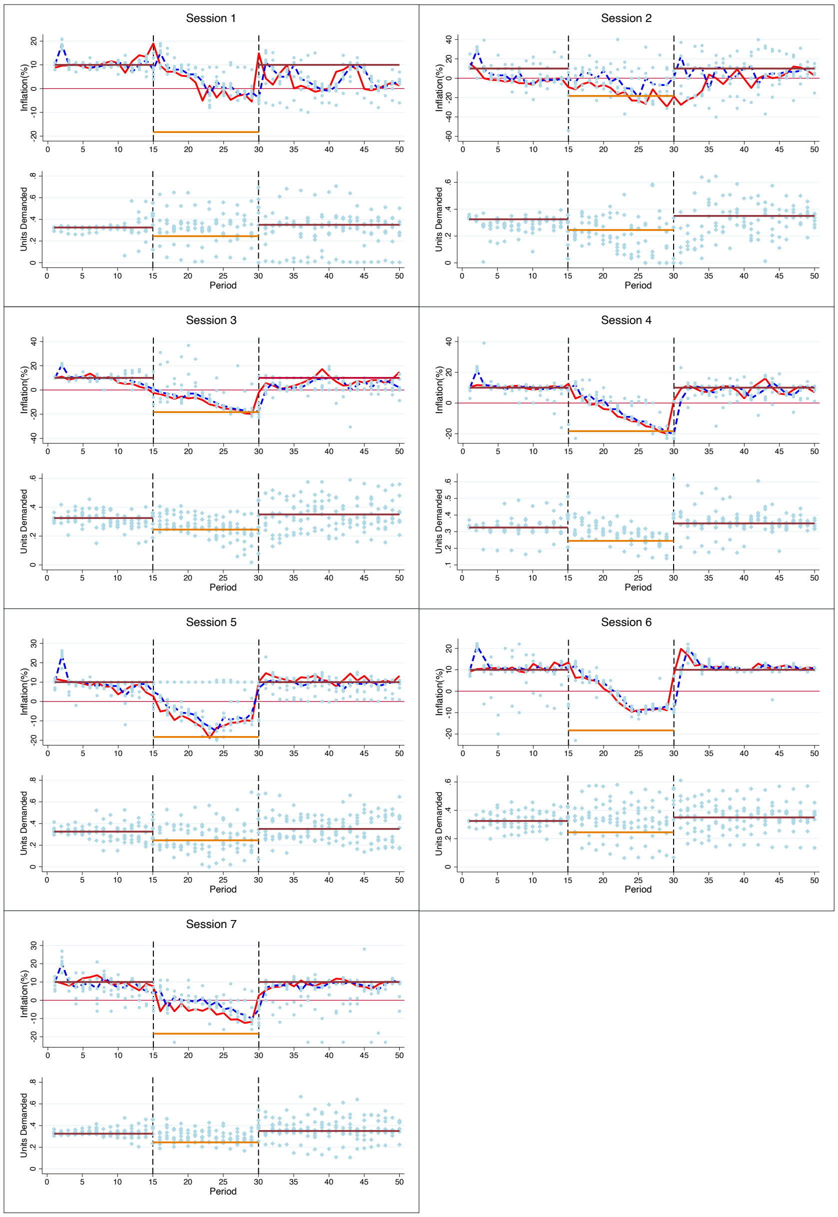


Figure 16: Individual-level inflation expectations (top, dots) and consumption (bottom, diamonds) data for *NegativeIR* sessions. Horizontal lines denote steady state levels of consumption and inflation. Maroon lines correspond to the central bank's inflation target, dark orange lines correspond the secular stagnation equilibrium. Dashed time series line denotes median inflation expectation. Solid time series line denotes actual inflation.

NegativeIR+Portfolio

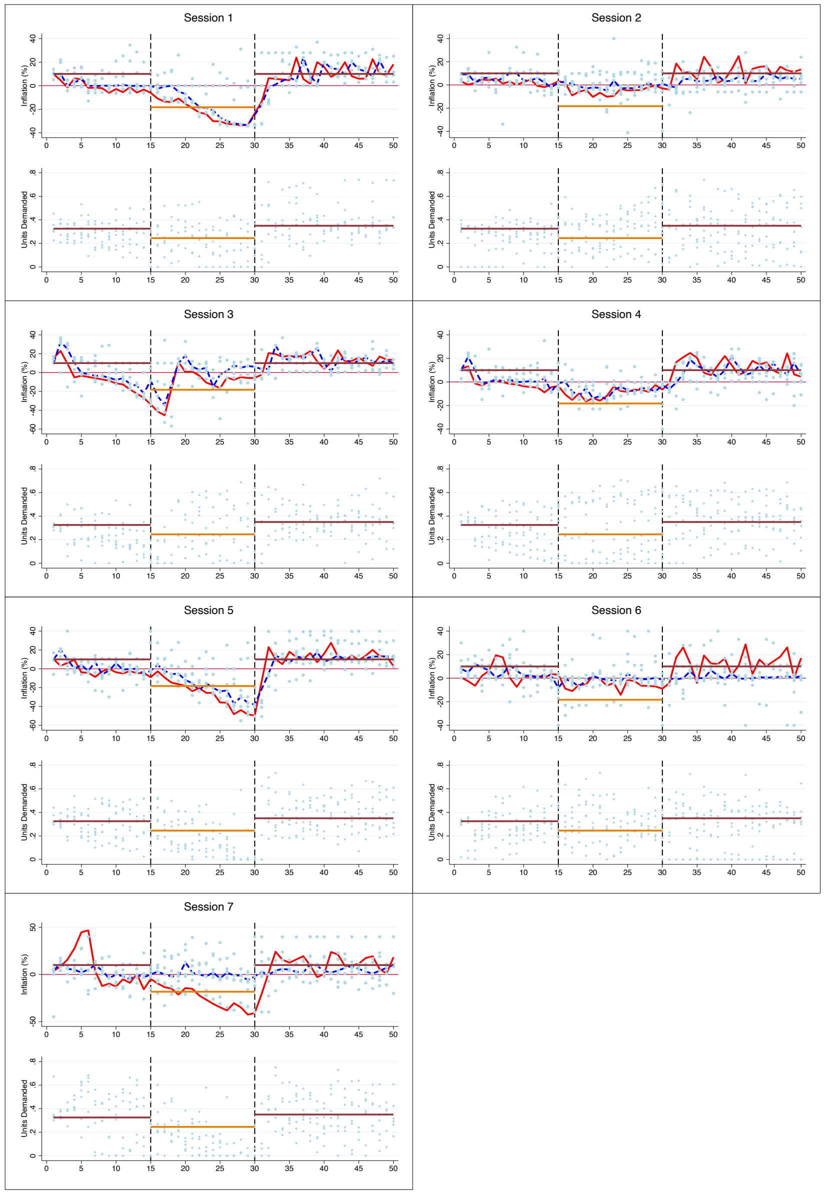


Figure 17: Individual-level inflation expectations (top, dots) and consumption (bottom, diamonds) data for *NegativeIR+Portfolio* sessions. Horizontal lines denote steady state levels of consumption and inflation. Maroon lines correspond to the central bank's inflation target, dark orange lines correspond the secular stagnation equilibrium. Dashed time series line denotes median inflation expectation. Solid time series line denotes actual inflation.

C Solving for Prices

This subsection of the appendix describes the algorithm we use to solve for prices in our experimental economies. First, we define the per-period, market-clearing price as:

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

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

$$P_t = \frac{C_Y + C_M + C_O}{Y^f}, \quad \Pi \geq 1 \tag{19}$$
$$P_t = \frac{C_Y + C_M + C_O}{Y_t}, \quad \Pi < 1. \tag{20}$$

We proceed by first supposing that prices are determined by Equation 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,

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

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

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

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:

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

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 Equation (20) determines prices in a given period is incorrect, and the algorithm instead sets prices according to Equation Equation (19).

D Central bank credibility

We measure the evolution of central bank credibility in each treatment. We classify a subject's nowcast or forecasting as exhibiting credibility if it is within 1 percentage point of the central bank's target. Figure 18 plots the share of participants exhibiting credibility in each period of each treatment.

At the beginning of all treatments, credibility in the central bank is considerably high. Credibility in Period 1 of Phase 1 exceeds 50% in *Baseline*, *HigherTarget*, and *NegativeIR*. It is lower in *NegativeIR+Portfolio*, at roughly 45% for nowcasts and 38% for forecasts. This lower credibility is not surprising given that participants are tasked with additional portfolio decision making in *NegativeIR+Portfolio*, and potentially direct less attention on the central bank's target.

Very rapidly, participants' credibility in the central bank's target declines as the economy evolves. In Phase 1, participant credibility averages between 21 and 36% in the first three treatments and 14 to 18% in our *NegativeIR+Portfolio*. This decline in credibility occurs despite inflation trending toward the inflation target in all treatments.

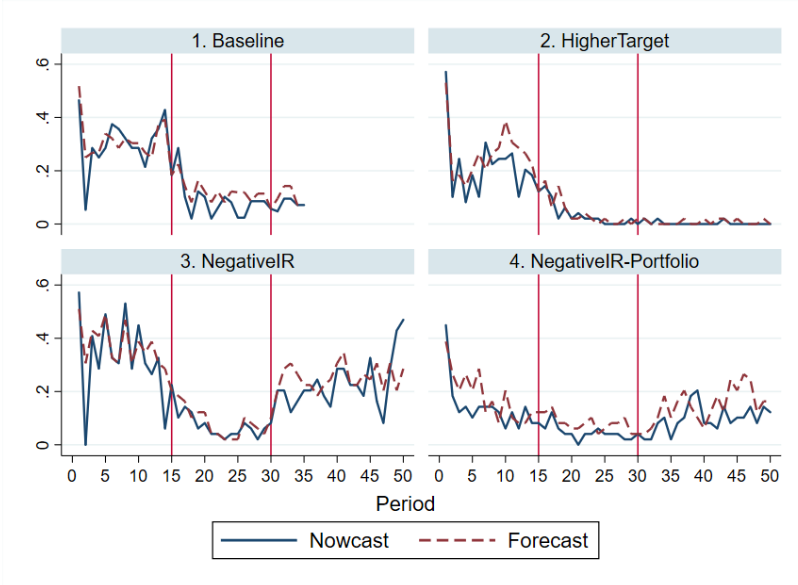


Figure 18: Share of participants exhibiting credibility in the central bank's inflation target

Rather than anchoring their expectations on the central bank's inflation target, most participants rely on recent historical inflation to form their forecast. See Section Section 5 for a detailed discussion of the distribution of forecasting heuristics.

On impact of the deleveraging shock, before participants have had an opportunity to change their real decisions, credibility in the central bank's inflation target falls significantly. Nowcast and forecast credibility in the target decline more than 20 percentage points in *Baseline* and 6-8 percentage points in *HigherTarget*. In *NegativeIR*, forecast credibility declines by 8 percentage points while nowcasts exhibit an increase in credibility of 16 percentage points. Overall, these results suggest that the credibility was fragile before entering Phase 2, and there was heightened uncertainty in the central bank's ability to achieve its target after the announcement of the deleveraging shock. We observe no notable change on impact of the deleveraging shock in *NegativeIR+Portfolio*, again indicative of limited attention on the target.

Following the deleveraging shock at the beginning of Phase 2, less than 15 percent of participants in any of the treatments deem the central bank's target as credible. What little credibility remains is notably persistent, and declines relatively slowly over Phase 2.

At the beginning of Phase 3 in *HigherTarget*, the central bank announces it is raising its inflation target from 10% to 30%. The announcement is met with complete skepticism. Only 2% of participants (one participant) is optimistic about the central bank's ability to achieve the new target.

After two periods into Phase 3, even this participant has lost credibility in the central bank.

The announcement of negative interest rates is also met with some initial skepticism. In *NegativeIR* credibility on impact of the announcement only results in a 2-percentage point increase in nowcasts and 6 percentage point increase in forecasts anchored on the 10% inflation target. With time the credibility in the target of 10% began to rise. Economies that had a higher proportion of participants perceive the target as credible experienced faster inflation, which in turn encouraged greater credibility. Likewise, credibility does not immediately jump in *NegativeIR+Portfolio*. Credibility remains quite muted, even as economies shoot past the central bank's inflation target. Instead, participants rely heavily on historical prices and inflation to formulate their expectations.

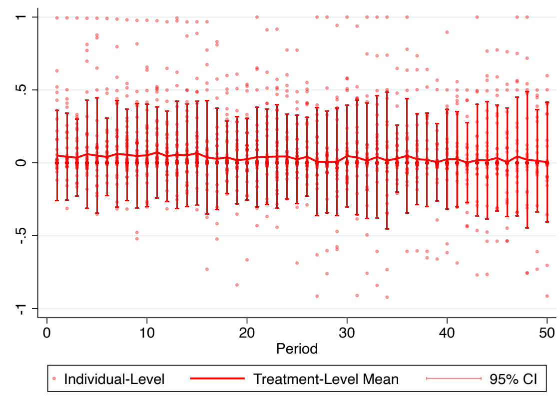
E Consumption Demand

We evaluate the determinants of middle-aged consumption demand in a series of random effects specifications. We estimate an Euler-like equation using data from our *HigherTarget*, *NegativeIR*, and *NegativeIR+Portfolio* treatments.

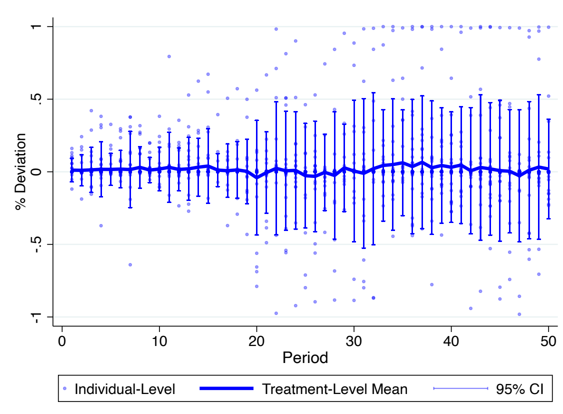
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Dep. Var.	HigherTarget and NegativeIR		HigherTarget	NegativeIR	NegativeIR+Portfolio		
$C^m_{i,t}/NI_{i,t}$	Phase 1	Phase 2	Phase 3	Phase 3	Phase 1	Phase 2	Phase 3
$C^m_{i,t-1}/NI_{i,t-1}$	-0.109	-0.211***	-0.079	0.012	-0.247***	-0.019	-0.043
	(0.10)	(0.05)	(0.06)	(0.07)	(0.06)	(0.05)	(0.07)
$C^m_{i,t-2}/NI_{i,t-2}$	0.692***	0.653***	0.797***	0.725***	0.524***	0.648***	0.623***
	(0.11)	(0.05)	(0.06)	(0.06)	(0.06)	(0.04)	(0.06)
$E_t i_t$	-0.132**	-0.414***	-0.694***	-0.537***	-0.557***	-0.091	-0.149*
	(0.06)	(0.12)	(0.21)	(0.08)	(0.09)	(0.88)	(0.08)
$E_t \pi_{t+1}$	0.301***	0.300***	0.272***	0.100	0.670***	0.354***	0.361**
	(0.12)	(0.05)	(0.06)	(0.11)	(0.19)	(0.11)	(0.16)
$ExpNegIR_t$				-2.147			3.764**
				(3.40)			(1.90)
α	19.592*	24.478***	14.055***	9.105*	32.357***	14.571***	13.800**
	(10.00)	(4.39)	(4.76)	(5.41)	(4.88)	(2.77)	(5.68)
N	1456	1568	1323	1029	637	735	980
χ^2	216.3	756.4	892.5	453.6	257.8	297.7	434.4

Table 7: This table presents results from a series of random effects panel regressions. The dependent variable, $C^m_{i,t}$ is the number of output units demanded by subject i in period t. $E_t i_t$ refers to expected nominal interest rate, $E_t \pi_{t+1}$ is the expected inflation rate, and $ExpNegIR_t$ is a dummy variable that takes the value of 1 if the expected nominal interest rate is negative, and 0 otherwise. α denotes the estimated constant. Robust standard errors are reported in parentheses. $^*p < 0.10$, $^{**}p < 0.05$, and $^{***}p < 0.01$.

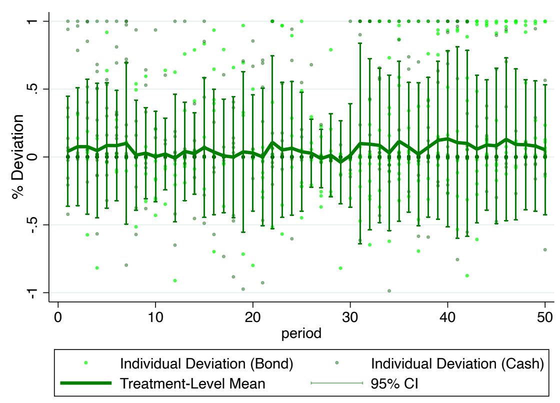
E.1 Consumption and Expectations



(a) HigherTarget



(b) NegativeIR



(c) NegativeIR+Portfolio

Figure 19: These sub-figures show individual-level deviations (dots) of consumption from the level of consumption that is optimal conditional on that individual's price expectations. Lines denote average deviations. Vertical bars denote a 95% confidence interval. This graphs show that, on average, consumption is consistent with expectations.