Learning, Changing Perceptions and the Anchoring of Expectations *

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Abstract

I explain the behavior of inflation, unemployment, and long-run inflation expectations in the post-war U.S. by estimating a forward-looking model in which private agents learn about structural fundamentals and the policymakers' stabilization preferences in real-time. Learning is structural: agents understand that aggregate economic dynamics result from their optimizing behavior under imperfect knowledge. Monetary policy is conducted optimally but private agents suspect that the policymakers' stabilization preferences are evolving, which they learn from observed policy behavior. This gives rise to a nonlinear filtering problem. The model provides a novel, information-theoretic explanation of how systematic monetary policy anchors expectations when agents are learning: an increasing emphasis on real-side stabilization has made the Fed's policy behavior more predictable, stabilizing long-run inflation expectations while at the same time rendering short-run expectations more susceptible to supply shocks. The model offers a new explanation for the recent post-Covid inflation surge and the "costless disinflation" that followed, shedding light on why it differed markedly from the crisis of the 1970s and 1980s.

Keywords: Inflation Stabilization, Monetary Policy, Interest Rates, Lucas Critique, New Keynesian
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1 Introduction

The post-pandemic surge in inflation—which saw U.S. CPI inflation rise to a 40-year high of 9.1% in June 2022—caught both the private sector and policymakers off-guard. As inflation remained elevated, comparisons were drawn to the *Great Inflation* of the 1970s–80s. Both periods were accompanied by a sharp rise in oil prices and supply disruptions, yet they yielded very different macroeconomic outcomes: a protracted inflationary spiral culminating in a painful disinflation in the 1980s versus a relatively swift "soft landing" that has characterized the US economy's recovery from the pandemic shock. A particularly striking feature of the recent surge has been the stability of long-run inflation expectations - even as private agents expected inflation to remain elevated in the short-run, their long-run expectations remained remarkably well-anchored (as seen in Figure 1).

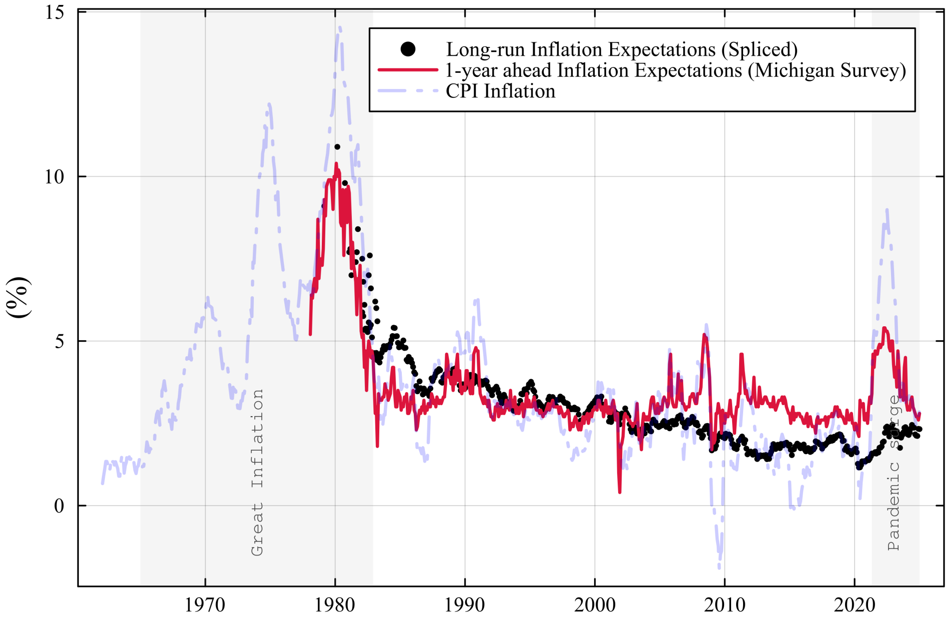

Figure 1: **Growing discord between short-run and long-run inflation expectations**

Note: Long-run Inflation Expectations series is constructed by splicing together 5-year ahead inflation expectations from Michigan Survey before 1982 and 10-year ahead inflation expectations from the Cleveland Fed afterwards (due to a shorter sample).

To explain these divergent outcomes, I develop a structural model with three key features. First, neither the private agents—households and firms nor central bank policymakers possess full information - their behavior is shaped by their *perceptions* regarding the fundamental state of the economy; which are formed based on interpreting macroeconomic outcomes through the lens of a forward-looking structural model, under *perpetual learning*. Second, monetary policy is conducted optimally under discretion reflecting a dual mandate, weighing between stabilizing inflation around a target and unemployment around its *natural* level. Third, agents suspect that the central bank's stabilization preferences may evolve over time, and they update their beliefs about these preferences based on observed policy behavior. Expectations are thus shaped by beliefs about both the structural features of the economy and the time-varying objectives of policymakers. Anchoring or de-anchoring of expectations thus results endogenously from learning. I estimate the model using monthly data on inflation, unemployment and the federal funds rate over the postwar period in the U.S., together with 10-year ahead inflation expectations from the Survey of Professional Forecasters (SPF).

The estimated model suggests that the contrasting outcomes of the two episodes are explained in large part by perceived shifts in the Federal Reserve's policy paradigm. During the 1970s, the Fed policymakers signaled little emphasis, through its conduct of policy on keeping the unemployment *gap* closed. From the agents' perspective, policy appeared to be guided almost entirely by a nominal target which was prone to idiosyncratic drifts - a tendency to deliberately inflate, presumably in an effort to artificially lower unemployment rate below its natural rate was observed: policy maintained an unduly expansionary stance particularly during recessions, even as supply side pressures loomed. The result was the de-anchoring of long-run inflation expectations as the agents, under their structural reasoning attributed the elevated levels of inflation to be a feature of systematic Fed policy rather than economic shocks: short-run and long-run inflation expectations shot up in unison.

Under Volcker, a sustained hawkish policy, despite relief from supply pressures signaled an effort to return to the old normal: a costly disinflation was achieved. In the following years, the Federal Reserve progressively demonstrated an increasing emphasis on stabilizing the unemployment gap, effectively tying systematic policy to the natural rate of unemployment—a structural fundamental. This shift has rendered policy behavior less prone to idiosyncratic activism and has made monetary policy more predictable. From the agents' perspective, idiosyncratic shifts in the inflation target have become less relevant to policy and as a result, they are slower to revise their beliefs regarding the target when they see errors in policy. This development is crucial to understand the recent "soft-landing". Even as the Fed demonstrated an unwillingness to respond to the inflation crisis for over a year (prompting concerns that the Fed was falling "behind the curve", for instance), their beliefs regarding the target that policy would seek to achieve remained remarkably anchored. However, they expected elevated inflation in the short-run owing to persistent supply shocks with little effort from policymakers to dampen the effects through adjustments on the real side. This mechanism is found to explain the peculiar discord between the behavior of short- and long-horizon inflation expectations over the recent years. The model delivers a key insight: when agents are learning structurally, anchoring policy behavior to an unobserved nominal target leaves long-run inflation expectations fragile to de-anchoring. Thus, short-run and long-run inflation stabilization are in tension.

The central bank's conduct of monetary policy is guided by the changing economic goals of the policymakers. In the model, monetary policy does not conform to any *instrument rule*, but is the result of an optimal policy problem under discretion given the policymakers' beliefs and policy preferences.[1]. Their policy decisions *reveal* information regarding their policy objectives. Hence, there is a non-trivial role for a "learning-channel" of monetary policy transmission in this environment, which operates by revealing information regarding the policymakers' stabilization preferences to the agents. Through this channel, policy influences agents expectations over all future horizons: there is *forward guidance* embedded into policy itself. When private agents observe discrepancies in policy behavior relative to their ex-ante expectations, they attribute part of it to be resulting from idiosyncratic policy errors which will get corrected in the future (policy falling "behind the curve"), and the rest to shifts in the policymakers' stabilization preferences and hence indicative of how policy will be conducted in the future (in this case, the agents are behind the curve and need to learn). Anchoring or de-anchoring of private agents expectations is an endogenous result of this learning process.

The literature on learning in macroeconomics highlights how agents update their beliefs in response to data *in real-time*, emphasizing the feedback from macroeconomic outcomes to agents' beliefs and decisions, something that full-information rational expectations abstracts from completely. However, much of the existing literature focuses on adaptive learning, where agents estimate reduced-form forecasting rules based on past data. In this setting, agents do not internalize the general equilibrium consequences of their beliefs, treating aggregate dynamics as exogenous to their own behavior. This paper models *structural* learning (see Williams (2003)), in which agents form expectations based on a forward-looking New-Keynesian model that describes aggregate dynamics as arising from their behavior. While knowledge is imperfect, expectations remain disciplined by rational forward-looking behavior, ensuring that beliefs are consistent with the underlying structural dynamics implied by optimization.

Importantly, macroeconomic shocks by themselves do not cause agents' expectations to de-anchor so long as policy responds in the way that the agents expect. When agents reason structurally, they know that under appropriate response of policy, the economy returns to the same long-run equilibrium. It is the interaction between macroeconomic surprises and the policy re-

[1] Instrument-rules such as the Taylor-rule are opaque regarding the trade-offs that policymakers actually face while deliberating about the conduct of monetary policy. It also causes an inconsistent asymmetry regarding how policy behavior is modeled, departing from the forward-looking optimizing framework modeling household and firm behavior. This critique is outlined in Svensson (2003)

sponse that determines whether expectations are anchored and whether they remain anchored, rather than macroeconomic shocks in isolation.

The model also sheds light on the state-dependent nature of agents' inference: informative signals about structural parameters arrive only in particular states of the world, often in discrete "lumps". Further, agents face the same kind of econometric challenges while reasoning in real-time that researchers face ex-post. For instance, agents revise their beliefs about the weight policymakers place on unemployment-gap stabilization primarily during episodes when large and persistent cost-push shocks create visible trade-offs between inflation and real activity. Similarly, learning about the slope of the structural Phillips curve is exceptionally slow due to a poor signal-to-noise ratio: unemployment gaps are typically small, and their relationship with inflation is obscured by cost-push shocks - meaningful information arrives almost exclusively during demand-driven recessions. The very arrival of information is state-dependent, which adds a key source of nonlinearity that models assuming full-information would entirely miss.

Related literature: The literature on learning in macroeconomics departs from the standard full-information benchmark and seeks to model how economic agents acquire information and form expectations. The literature has largely focused on adaptive learning (see Evans and Honkapohja (2001) for overview and applications) where agents use simple forecasting rules, typically reduced-form VARs to form expectations. Adaptive learning by private agents has been proposed as an explanation of the observed persistence in macroeconomic series that does not rely on ad-hoc frictions such as indexation to past prices and habit formation in consumption (see Milani (2007) and Erceg and Levin (2003)).

This paper is an empirical application of learning to study macroeconomic behavior in the post-war U.S., and is closely related to the literature examining how private agents' and policymakers' learning contributed to the Great Inflation of the 1970s and 1980s (e.g., Bullard and Eusepi (2005); Primiceri (2006); Sargent, Williams and Zha (2006),Orphanides and Williams (2005)). More broadly, it connects to the literature on how the private sector learns from monetary policy behavior. For instance, Melosi (2016) examines the signaling role of policy in a DSGE framework, where monetary policy is informative about aggregate shocks. By contrast, in this paper, the only source of information asymmetry arises from the private sector's inability to observe the central bank's stabilization preferences. Other related work has explored how agents infer policy targets from macroeconomic data (e.g., Kozicki and Tinsley (2005); Erceg and Levin (2003); Orphanides and Williams (2006)). However, much of this literature relies on adaptive learning, in which agents form beliefs using reduced-form forecasting rules based on historical correlations. In contrast, the learning behavior in this paper is grounded in a structural, forward-looking framework rooted in New Keynesian principles, where agents understand and internalize the effects of their expectations on macroeconomic outcomes.

The causes of the Great Inflation and the subsequent Great Moderation have been the subject of long-standing debate. One school attributes the volatility of the 1970s–80s era to "bad luck": a sequence of large, adverse non-policy shocks (e.g., Sims and Zha (2006); Bernanke and Mihov (1998)). Under this view, the structure of the economy and policy rules remained largely stable; it was the volatility of exogenous shocks that changed. This view implies that monetary policy made little fundamental progress—if similar shocks were to recur, so would similar outcomes. However, I find that how agents perceive the Fed's stabilization policy based on observed policy behavior has changed drastically which has had a huge bearing on the macroeconomic outcomes ever since the Great Moderation and beyond.

An alternative view emphasizes policy errors. Clarida, Gali and Gertler (2000), Taylor (1993) and Lubik and Schorfheide (2004) argue that the shift to systematic anti-inflation policy by the Fed under the chairmanship of Paul Volcker was central to the subsequent stability. DeLong (1996) and Romer and Romer (2002) provide narrative evidence that policymakers in the 1970s were misled by a perceived long-run tradeoff between inflation and unemployment. Some papers study whether these policy mis-steps by the Fed were a result of "wrong" kind of incentives. For example Christiano and Gust (2000) invokes the idea that the Fed fell into an "expectations trap", lacking the incentives to take decisive action to rein in inflation during the 70s. At least from the private agents' perspective, I find that policy errors were made. The model I present does not take a stance on the *source* of these errors, but rather, the focus here is on the *consequences*: how these errors shaped the agents' views regarding the Fed's incentives and led to inflation through the expectations channel.

Lack of Fed credibility has been proposed as another explanation for the Great Inflation. King and Lu (2022) and Debortoli and Lakdawala (2016) find that lack of commitment to low inflation in 70s made the disinflation much more costly. A related strand of literature has studied the mechanisms through which long-run inflation expectations get *anchored*. Carvalho, Eusepi, Moench and Preston (2023) and Gati (2023) describe anchoring in terms of how agents weight recent inflation data when updating their beliefs about the long-run mean of inflation based on past forecast errors (forecast-switching). In this paper, anchoring directly results from agents learning about the central bank's stabilization preferences based on the *policy response* to inflation rather than the behavior of inflation itself.

This paper contributes to the debate by offering a framework that disentangles these three explanations and sheds light on how each of these contributed to shaping the two prominent inflationary episodes in the post-war period in the U.S.

Outline: In Section 2, I motivate the agents' perceived structural model describing the economy as perceived by private agents which they use to reason about the macroeconomic environment that they face. In Section 3, I describe how agents recursively update their beliefs regarding the policy-invariant structural variables in their model conditional on macroeconomic observations. In Section 4, I describe the conduct of monetary policy from the perspective of the agents and describe how they update beliefs regarding the policymakers' stabilization preferences conditional on observed nominal interest rates. In Section 5, I describe the estimation methodology and the data. In Section 6, I discuss how the agents' beliefs have evolved during the postwar period in the U.S. under learning followed by concluding remarks.

2 A forward looking model under imperfect knowledge

Here I begin by describing the information structure of the economy, defining the set of signals that agents observe at any time, based on which they form their beliefs and make decisions. Then, I derive the agents' perceived law of motion describing the structural dynamics of the macroeconomic aggregates under imperfect knowledge.

2.1 Information structure and learning

Time is discrete ($t = 0, 1, 2, 3, \dots$). Under the information structure in the model, neither the latent structural parameters or the structural shocks are directly observed by the agents. The only relevant signals available to them comes in the form of the realizations of the aggregate inflation rate, unemployment rate and the nominal interest rate. At the beginning of each period t, firms and households make their decisions conditional on the history of signals observed until that point. The period-t inflation π_t and unemployment rate u_t then realize and are observed by the agents. The central bank then sets the interest rate i_{t+1} in anticipation of future outcomes. The agents interpret the policy decision and form beliefs regarding the policymakers' stabilization preferences. Thus, at the end of period-t, π_t, u_t and i_{t+1} are realized and observed by all agents.

The entire history of aggregate signals observed by agents up to (and including) period t_0 is denoted by:

$$\mathcal{H}^{t_0} = \{i_{t+1}\}_{t=-\infty}^{t_0} \cup \{z_t\}_{t=-\infty}^{t_0}$$

where $z_t = [\pi_t, u_t]'$ is the vector of realizations of inflation and unemployment, and i_{t+1} denotes the interest-rate policy set in period-t.

2.2 The agents' perceived model of aggregate dynamics

Following New Keynesian principles, I derive the log-linearized equations describing the structural dynamics of the economy from the perspective of the agents, based on a model of optimizing behavior by firms and households under imperfect knowledge. I assume that all private agents firms and households have common beliefs regarding the policy-invariant latent structural drivers of the economy, formed conditional on the same data and model.[2] I denote the private agents expectations conditional on $t-1$ history $\mathcal{H}^{t-1}$ as E^P_{t-1}.

2.2.1 Aggregate demand: Households' consumption smoothing problem

Consider the problem of a representative household who derive utility from consumption and save in nominal bonds B_t in every period t conditional on their beliefs formed based on observed history $\mathcal{H}^{t-1}$:

$$\max \; E^P\left[\sum_{k=0}^{\infty} \beta^k \frac{C_{t+k}^{1-\sigma}}{1-\sigma}\right] \tag{1}$$

where C_t is consumption, β is a discount factor, $\sigma > 0$ is the inverse of the intertemporal elasticity of substitution

The household's budget constraint in nominal terms is:

$$P_t C_t + B_t = (1 + i_{t-1}) B_{t-1} + W_t + T_t + \Pi_t \tag{2}$$

where P_t is the aggregate price level, B_t are nominal bond holdings, i_{t-1} is the nominal interest rate in period $t-1$, W_t denotes their nominal wage-income, T_t denote lump-sum government transfers and Π_t denotes profits from the ownership of firms.

In this setting, the only dynamic decision that the representative household makes is the savings

[2] I abstract from heterogeneity in agents' belief-formation process.

decision, which leads to the following Euler equation:

$$C_t^{-\sigma} = \beta E^P \left[C_{t+1}^{-\sigma} \frac{1+i_t}{1+\pi_{t+1}} | \mathcal{H}^{t-1} \right] \tag{3}$$

where $1 + \pi_{t+1} = P_{t+1}/P_t$ is the aggregate inflation rate.

Since there is no investment or government expenditure in the model, all output is consumed every period $Y_t = C_t$, log-linearizing around the steady state, we get the aggregate-demand IS-curve:

$$\hat{y}_t = E_{t-1}^P[\hat{y}_{t+1}] - \frac{1}{\sigma}(i_t - E_{t-1}^P[\pi_{t+1}] - \rho) \tag{4}$$

where $\hat{y}_t$ denotes the log-deviation of output from its steady-state. $\rho = -\log \beta$. Defining the *ex-ante* real interest rate as $r_t = i_t - E_{t-1}^P[\pi_{t+1}]$, the IS curve may be more compactly written as:

$$\hat{y}_t = E_{t-1}^P[\hat{y}_{t+1}] - \frac{1}{\sigma}(r_t - \rho) \tag{5}$$

At some hypothetical real interest rate, output would continue along the trend path, y_t^n (or the "natural" level of output) absent cyclical fluctuations. We call this the natural rate of interest and denote it by r_t^n. Log-deviations of the natural level of output $\hat{y}_t^n$, follow:

$$\hat{y}_t^n = E_{t-1}^P[\hat{y}_{t+1}^n] - \frac{1}{\sigma}(r_t^n - \rho) \tag{6}$$

Subtracting Equation 6 from Equation 5 yields:

$$\hat{y}_t - \hat{y}_t^n = E_{t-1}^P[\hat{y}_{t+1} - \hat{y}_{t+1}^n] - \frac{1}{\sigma}(r_t - r_t^n) \tag{7}$$

Denoting $\hat{y}_t - \hat{y}_t^n$ as output gap $\tilde{y}_t$, we may re-write the dynamic IS curve in terms of output gap as:

$$\tilde{y}_t = E_{t-1}^P[\tilde{y}_{t+1}] - \frac{1}{\sigma}(i_t - E_{t-1}^P[\pi_{t+1}] - r_t^n) \tag{8}$$

2.2.2 Aggregate supply: Firms' pricing problem

Firm price-setting under dispersed information Every period t, all firms automatically adjust their prices by the perceived trend inflation rate conditional on their $t-1$ information set, given by π^{*P}_{t-1}.[3] The perceived level of trend inflation does not enter firms' pricing problem since all firms have the same beliefs and adjust to the same perceived trend rate every period. However, relative price adjustments are subject to Calvo frictions. Only a constant fraction $(1-\theta)$ of firms are able to adjust their price every period (adjustment frequency θ is common knowledge). All firms set prices in order to earn a constant markup over their nominal marginal cost. The steady-state relative price of each firm is unity. For concision, we express their optimal price setting problem in terms of log-deviations from steady-state.

In the absence of Calvo frictions, log-deviations in their optimal reset are equal to the sum of log-deviations in the aggregate price-level, denoted as $\hat{p}_t$ and log-deviations in their real marginal cost, $mc_t(j)$.

$$\hat{p}^*_t(j) = \hat{p}_t + \hat{mc}_t(j)$$

Consider the problem of price-setting by monopolistic firms in the standard New-Keynesian setting, where they solve for their optimal reset price while subject to Calvo frictions. Due to these frictions, the firm must set prices so as to receive a constant markup *in expectation*.

$$\hat{p}^*_t(j) = (1-\beta\theta)E^j\Big[\sum_{k=0}^{\infty}(\beta\theta)^k(\hat{p}_{t+k} + \hat{mc}_{t+k}(j))|\mathcal{H}^{t-1}\Big] \tag{9}$$

where $E^j[\cdot]$ denotes the expectation operator conditional on firm j's information set. The firms' information set is the same as that of the representative households, and is denoted by $\mathcal{H}^{t-1}$

Additionally, each firm observes its own real marginal cost $\hat{mc}_t(j)$ at the beginning of the period. $\hat{mc}_t(j)$ is composed of an economy-wide component $\hat{mc}_t$ plus an idiosyncratic firm-specific *i.i.d* (across firms and across time) component, $\varepsilon_t(j)$ with *large* variance.[4]

$$\hat{mc}_t(j) = \hat{mc}_t + \varepsilon_t(j) \quad \varepsilon_t(j) \sim N(0, \sigma^2_\varepsilon)\ \forall\ j \in (0,1) \tag{10}$$

Under knowledge that it can only reset with probability $1-\theta$ any period in the future would, the optimal price is given by:

[3]This assumption permits the model to be log-linearized around the zero inflation steady state despite non-zero trend inflation. Inflation here refers to inflation beyond this "normal" level.

[4]This assumption is motivated by the observation that firm-specific price changes are much more volatile as compared to fluctuations in the aggregate price-level. This modeling framework is based on Nimark (2008).

$$\hat{p}_t^*(j) = (1-\beta\theta)E^j\Big[\sum_{k=0}^{\infty}(\beta\theta)^k(\hat{p}_{t+k} + \hat{mc}_{t+k}(j))|\mathcal{H}^{t-1} \cup \hat{mc}_t(j)\Big] \tag{11}$$

Dispersed information assumption: The firm is atomistic, its own marginal cost reveals negligible information about innovations to the economy-wide real marginal costs or changes in the price level p_t. Thus, their expectations regarding these are unchanged from those formed based on $\mathcal{H}^{t-1}$ and common across firms, denoted as E_{t-1}^P. Hence:

$$E^j[\hat{p}_t + \hat{mc}_t(j)|\mathcal{H}^{t-1} \cup \hat{mc}_t(j)] = E_{t-1}^P\hat{p}_t + \hat{mc}_t(j) \tag{12}$$

$$E^j[\hat{p}_{t+k} + \hat{mc}_{t+k}|\mathcal{H}^{t-1} \cup \hat{mc}_t(j)] \approx E_{t-1}^P\hat{p}_{t+k} + E_{t-1}^P\hat{mc}_{t+k} \; \forall \; k \geq 0 \tag{13}$$

Log-deviations in firm j's optimal reset price may be written as:

$$\hat{p}_t^*(j) = (1-\beta\theta)(E_{t-1}^P\hat{p}_t + \hat{mc}_t(j)) + \beta\theta E_{t-1}^P\hat{p}_{t+1}^* \tag{14}$$

All firms face the same price-setting problem, just observe a different marginal cost signal. Aggregating across all firms yields:

$$\hat{p}_t^* = (1-\beta\theta)(E_{t-1}^P\hat{p}_t + \hat{mc}_t) + \beta\theta E_{t-1}^P\hat{p}_{t+1}^* \tag{15}$$

Under a Calvo-probability of price adjustment of $(1-\theta)$, evolution of the aggregate price index satisfies:

$$\hat{p}_t = \theta\hat{p}_{t-1} + (1-\theta)\hat{p}_t^* \tag{16}$$

Combining Equation 15 and Equation 16 yields the aggregate supply condition in terms of the aggregate inflation rate $\pi_t = \hat{p}_t - \hat{p}_{t-1}$:

$$\pi_t = \beta E_{t-1}^P\pi_{t+1} + \frac{(1-\theta)(1-\beta\theta)}{\theta}\hat{mc}_t + \frac{(1-\theta)^2(1-\beta\theta)}{\theta}(E_{t-1}^P\hat{mc}_t - \hat{mc}_t) \tag{17}$$

The expectational errors manifest due to the fact that the economy-wide real marginal cost is not perfectly forecast-able. If the firms' private signal revealed $\hat{mc}_t$ perfectly, we would go back to the standard New-Keynesian Phillips curve formulation and the expectational error term goes away. Also, it must be noted that the smaller the degree of price-stickiness (θ), the larger the contribution of these errors to actual inflation.

Pro-cyclicality of marginal cost The economy-wide real marginal cost mc_t is unobservable. Agents can only infer it from aggregate realizations. The structural dynamics driving the economy-wide component of real-marginal costs are unknown, but agents perceive a pro-cyclical relationship: when output is above the flex-price level, it puts upward pressure on real marginal costs across all firms. Variation in $\hat{mc}_t$ above and beyond this pro-cyclical channel are attributed to economy-wide supply shocks, s_t. Hence, they perceive the following structural relationship:

$$\hat{mc}_t = \gamma\tilde{y}_t + s_t$$

where s_t denotes the supply shock, assumed to follow a mean-zero stationary process and independent of the unemployment-gap $\tilde{y}_t$. $\gamma > 0$ represents the link between economy-wide real marginal cost and the cyclical fluctuations in unemployment. It is assumed to be constant, but unknown.

The agents' reasoning motivates the following forward-looking Phillips curve:

$$\pi_t = \beta E^P_{t-1}[\pi_{t+1}] + \psi\tilde{y}_t + \xi_t \tag{18}$$

where (i) $E^P_{t-1}[\pi_{t+1}]$ denotes the private-sector's expectation of inflation in period $t+1$ conditional on history of signals $\mathcal{H}^{t-1}$ (ii) ψ represents the sensitivity of inflation to current output-gap. Agents assume κ is constant but unknown and hence learn about it every period. (iii) ξ_t is a cost-push shock composed of the supply-shock s_t and the expectational error.

The $\psi\tilde{y}_t$ term describes the contemporaneous link between inflation and the "real" side of the economy. The output gap, $\tilde{y}_t$ contemporaneously affects inflation through the slope parameter ψ. The relationship implies that output, when above its natural level ("potential") exerts inflationary pressure on the economy.

The cost-push shock ξ_t captures the component of inflationary pressures arising from factors over and beyond real economic activity. Agents allow for the possibility that the cost-push shocks have a persistent component. Hence they decompose the cost-push shock, ξ_t to into a *persistent* AR(1) component denoted by ξ^P_t, with large persistence ρ and a *transitory* i.i.d normal component ξ^T_t.

$$\xi_t = \xi^P_t + \xi^T_t, \quad \xi^T_t \sim iid\, N(0, \sigma^2_{\xi,T})$$

The persistent component is perceived to evolve as:

$$\xi_t^P = \rho \xi_{t-1}^P + \varepsilon_t^P, \quad \varepsilon_t^P \sim iid\, N(0, \sigma_{\xi,P}^2)$$

Only the persistent component ξ_t^P affects future outcomes. Agents must learn about this shock to form expectations about the future. ξ_t^T is irrelevant for dynamics and just functions as noise.

Natural rate hypothesis: Agents in the model a-priori assume that monetary policy cannot systematically drive real variables once prices and expectations fully adjust. Under the natural rate hypothesis, the output and the real interest rate attain their natural levels in the long-run, beyond the control of monetary policy. This is equivalent to agents assuming that the discount-factor $\beta \to 1$ so that expectations-augmented Phillips curve is vertical in the long-run.[5] Agents reason that in the long run, monetary policy can only create inflation, not drive output gaps.

2.2.3 Measuring real-economic activity

According to the structural model, real economic activity, as measured by the output gap forms the important structural link between aggregate inflation and interest rates. However, it is not directly observable. It must be inferred based on real time indicators of economic activity. I assume that the only real indicator in this economy, informing agents about the state of aggregate demand is the unemployment rate. This is because unemployment rate is a more salient variable than output or GDP and is directly part of the dual mandate that most modern central banks in the world, including the Fed follow. For this reason, it is useful to re-frame the model in terms of unemployment gaps, defined as the difference between the realized unemployment rate and the one that would prevail under flexible prices, or the "natural" rate of unemployment.

Agents posit a linear relationship between the output gap and the unemployment gap[6] defined as the difference between the unemployment rate and the natural rate of unemployment (empirically, the "trend" component of unemployment rate): $x_t = u_t - u_t^n$, we have

$$\tilde{y}_t = -\eta x_t$$

where η is referred to as the Okun's law coefficient.

This yields the following dynamic IS-curve representing the law of motion of the unemployment-

[5]Since otherwise, the long-run unemployment-gap must be non-zero from Equation 20.

[6]This relationship is sometimes referred to as Okun's law. Ball et al. (2017) find that it has been relatively stable across time.

gap:

$$x_t = E^P_{t-1}x_{t+1} + \tau(i_t - E^P_{t-1}\pi_{t+1} - r^n_t) \tag{19}$$

where $\tau = 1/(\sigma\eta)$ represents the ratio of the intertemporal elasticity of substitution and the Okun's law coefficient. τ is assumed to be constant and known to all agents.

Similarly, the expectations-augmented Phillips curve in terms of unemployment gap becomes:

$$\pi_t = E^P_{t-1}\pi_{t+1} - \kappa x_t + \xi_t \tag{20}$$

where $\kappa = \psi\eta$ is assumed to be a constant that the agents learn about.

3 Learning: Latent structure of the economy

Every period, conditional on the observed unemployment rate u_t, all agents infer the contemporaneous unemployment gap and the natural rate of interest. Then they conditionally update their beliefs about the slope of the Phillips curve κ, and the persistent supply shock ξ^p_t based on the observed aggregate inflation rate π_t. Thus, they update their beliefs about all the variables describing the latent structure of the economy in their model, every period. The rest of the section discusses the mechanics of this part of their learning behavior.

3.1 Learning and the Anticipated Utility assumption

This paper takes the anticipated utility approach to learning described in Kreps (1998). Under this assumption, agents form "certainty-equivalent" estimates of the relevant state-variables every period and treat their best estimates as if they were constants known with certainty when making decisions. Agents disregard the possibility of updating their current estimates in the future. This assumption is widely used in the literature on learning in macroeconomics (see Evans and Honkapohja (2001)). It allows us to surmount the computational challenges associated with solving the dynamic problem in the full Bayesian setting. Cogley and Sargent (2008) demonstrate how the anticipated utility assumption provides an excellent approximation to Bayesian decision-making in a wide class of problems.

3.2 Inferring the unemployment gap x_t

Conditional on the observed unemployment rate u_t, agents update their estimate of the natural rate u_t^n according to the univariate smoothing algorithm:

$$u_t^n = u_{t-1}^n + g_u(u_t - u_{t-1}^n) \tag{21}$$

The natural rate is inferred from a backward-looking filter based on the unemployment rate, putting more weight on recent observations. The gain coefficient g_u determines the degree to which shifts in the unemployment rate are attributed to shifts in the natural rate of unemployment. g_u is constant and known to all agents.

From the natural rate hypothesis, $\lim_{h\to\infty} x_{t+h} = 0$. Hence, the unemployment rate is always expected to converge to the natural rate u_t^n in the long-run equilibrium, consistent with the update-rule Equation 21.[7]

Agents' estimate of the contemporaneous unemployment gap is:

$$x_t = u_t - u_t^n$$

I abstract from issues of real-time mis-measurement and data revisions. I do however find that the agents' real-time measure inferred from data lines up quite well with series that are revised retroactively (the CFNAI index as an example, see Appendix D) suggesting that these issues are not of large consequence over the sample period.

[7] Staiger, Stock and Watson (1997) and Orphanides and van Norden (2002) show that such univariate algorithms deliver estimates that are essentially indistinguishable from the ones derived under more sophisticated procedures. Similarly, Kamber, Morley and Wong (2018) demonstrate that economic slack-measures derived from similar univariate procedures can be robust to revisions and are found to be in line with more refined measures of real-time economic activity (such as the Chicago Fed National Economic Activity Index).

3.3 Recursive updating

Agents' perceived model of aggregate dynamics: The equations describing the aggregate laws of motion of the economy from the perspective of the private agents are:

$$x_t = E^P_{t-1}[x_{t+1}] + \tau(i_t - E^P_{t-1}[\pi_{t+1}] - r^n_t)$$

$$\pi_t = E^P_{t-1}[\pi_{t+1}] - \kappa x_t + \xi^P_t + \xi^T_t, \quad \xi^T_t \sim iid\, N(0, \sigma^2_{\xi,T})$$

$$\xi^P_t = \rho \xi^P_{t-1} + \varepsilon^P_t\ , \quad \varepsilon^P_t \sim iid\, N(0, \sigma^2_{\xi,P})$$

Conditional on the observed aggregate inflation rate π_t and the unemployment gap x_t inferred from u_t based on the de-trending procedure, agents update their beliefs regarding κ, ξ^p_t and r^n_t recursively every period treating $[\sigma^2_{\xi,T}, \sigma^2_{\xi,P}, \tau, \rho]$ as known constants.

Learning the natural rate of interest r^n_t: Conditional on the inferred unemployment-gap x_t, the contemporaneous estimate of the natural rate of interest $r^n_{t|t}$[8] is given by the dynamic IS curve (Equation 19):

$$r^n_{t|t} = \tau^{-1}(E^P_{t-1}x_{t+1} - x_t) + i_t - E^P_{t-1}\pi_{t+1}$$

Further, agents assume that r^n_t follows a Martingale, so that $r^n_{t+1|t} = r^n_{t|t}$

Learning ξ^P_t and κ: Given the unemployment-gap x_t, beliefs about the persistent component of the cost-push shock ($\xi^P_{t|t}$) and the slope of the Phillips curve ($\kappa_{t|t}$) are recursively updated every period based on observed aggregate inflation rate π_t.

Agents face a signal-extraction problem in real time: they cannot immediately distinguish whether an inflation surprise was driven by the unemployment-gap (due to mis-perception of the slope κ), persistent supply shocks—relevant for expectations—or transitory supply shocks, which are irrelevant for expectations. Accordingly, agents revise their beliefs about ξ_t and κ according to the following equations:

The observation equation, relating aggregate inflation to ξ_t and κ in the agents' perceived model

[8] As we shall see, $r^n_{t|t}$ is irrelevant for expectations since stabilizing against demand shocks is costless and poses no policy trade-off.

is given by:

$$\pi_t - E_{t-1}^P \pi_{t+1} = \begin{pmatrix} -x_t & 1 \end{pmatrix} \begin{pmatrix} \kappa \\ \xi_t^P \end{pmatrix} + \xi_t^T, \quad \xi_t^T \sim N(0, \sigma_{\xi,T}^2).$$

The state-transition equation specifying the agents' prior regarding how the state variables κ and ξ_t^p evolve over time is given by:

$$\begin{pmatrix} \kappa \\ \xi_t^P \end{pmatrix} = \begin{pmatrix} 1 & 0 \\ 0 & \rho \end{pmatrix} \begin{pmatrix} \kappa \\ \xi_{t-1}^P \end{pmatrix} + \begin{pmatrix} 0 \\ \epsilon_t^P \end{pmatrix}, \qquad \epsilon_t^P \sim N(0, \sigma_{\xi,P}^2)$$

Note that the state-transition equation reflects the agents' prior that the true slope κ is time-invariant.

4 Learning: Policymakers' stabilization preferences

Given their beliefs regarding the latent structural variables - the slope of the Phillips curve $\kappa_{t|t}$, the persistent supply shock $\xi_{t|t}^p$ and the natural rate of interest $r_{t|t}^n$, the agents interpret the period-t policy decision i_{t+1} and learn about the policymakers' stabilization preferences underlying policy behavior. The next subsection describes the policymakers' optimal policy problem under a dual mandate.

4.1 Monetary policy

The private-agents assume that the central bank conducts monetary policy optimally under discretion, having the same beliefs about the policy-invariant latent structural variables as them formed based on the same economic model and data. The central bank has a dual mandate characterized by the following loss function[9]:

$$\mathcal{L}_t = \sum_{j=1}^{\infty} [(\pi_{t+j|t} - \pi_t^*)^2 + \lambda_t x_{t+j|t}^2] \tag{22}$$

[9]I assume that the central bank's policy preferences are not fundamentally incompatible. Hence policymakers have no incentive to sustain a level of unemployment below the natural rate.

where $\pi_{t+j|t}$ and $x_{t+j|t}$ denote the central bank's forecasts of inflation and the unemployment gap for period $t+j$ formed in period-t after the contemporaneous π_t, x_t have been realized. Here, π_t^* and λ_t represent the policymakers' period-t stabilization preferences: their inflation target and the relative weight they place on unemployment-gap stabilization. Private agents do not observe these and assume that they are subject to slow innovations over time. Their beliefs regarding these parameters conditional on $\mathcal{H}^t$ are denoted by π_t^{*P} and λ_t^P.

The central bank in its period-t decision cycle chooses the one-period ahead unemployment gap plan $x_{t+1|t}$. Private agents' period-t expectations regarding future inflation and unemployment gaps formed prior to observing the policy decision (denoted by $E_t^{P-}\pi_{t+j}$ and $E_t^{P-}x_{t+j}$) are observed by the central bank.[10] Every period, the central bank chooses $x_{t+1|t}$ which solves its period-t static optimization problem taking the observed private-sector expectations as given, conditional on the following structural constraint implied by the Phillips curve:

$$\pi_{t+1|t} = E_t^{P-}\pi_{t+2} - \kappa_{t|t}x_{t+1|t} + \xi_{t+1|t} \tag{23}$$

The optimal unemployment gap plan $x_{t+1|t}$ is given by the targeting rule:

$$x_{t+1|t} = \frac{\kappa_{t|t}}{\lambda_t}(\pi_{t+1|t} - \pi_t^*) \tag{24}$$

Equation 24 describes the textbook "lean against the wind" policy solution where the central bank reacts by creating a positive unemployment gap if it expects inflation to be above its target in the following period.

Using Equation 23 and Equation 24, the central bank's one-period ahead inflation and unemployment gap plan must satisfy:

$$\pi_{t+1|t} = \pi_t^* + \frac{\lambda_t}{\lambda_t + \kappa_{t|t}^2}(E_t^{P-}\pi_{t+2} + \xi_{t+1|t} - \pi_t^*) \tag{25}$$

$$x_{t+1|t} = \frac{\kappa_{t|t}}{\lambda_t + \kappa_{t|t}^2}(E_t^{P-}\pi_{t+2} + \xi_{t+1|t} - \pi_t^*) \tag{26}$$

Equation 25 shows that when $\lambda_t > 0$, the central bank allows inflation to rise above its target when faced with a persistent cost-push shock. Deviations of inflation from the target, arising from private agents' inflation expectations and persistent cost-push shocks are accommodated to an extent. The larger λ_t is, the greater the accommodation, with $\lambda_t \to \infty$ characterized by

[10] E_t^{P-} denote expectations formed after the realization of the contemporaneous aggregates $z_t = [\pi_t, u_t]$ but before the period-t policy decision, and are thus formed conditional on beliefs $\kappa_{t|t}, \xi_{t|t}^p, \pi_{t-1}^{*P}, \lambda_{t-1}^P$.

a situation where the central bank can no longer push back against private agents' expectations anymore. This represents an "expectations-trap" in the sense of Christiano and Gust (2000) that policymakers fall into where any real-side adjustment is deemed too costly. In the same vein, Equation 26 shows that the extent of unemployment gap adjustments that policymakers will engage in, is decreasing in λ_t.[11]

4.2 Private sector expectations in a learning equilibrium

Under rationality, private-agents' expectations for all future horizons must be consistent with their structural model of inflation dynamics:

$$E^P[\pi_{t+j}] = E^P[\pi_{t+j+1}] - E^P[\kappa x_{t+j}] + E^P[\xi_{t+j}] \; \forall \; j \geq 1$$

The constraint above yields the following forward looking system of equations that their expectations at any period t must satisfy:

$$E_t^P \pi_{t+j} = E_t^P \pi_{t+j+1} - \kappa_{t|t} E_t^P x_{t+j} + \rho^j \xi_{t|t}^P$$

From the "lean against the wind" targeting rule, their unemployment gap expectations are:

$$E_t^P x_{t+j} = \frac{\kappa_{t|t}}{\lambda_t^P + \kappa_{t|t}^2}(E_t^P \pi_{t+j+1} + \rho^j \xi_{t|t}^P - \pi_t^{*P}) \tag{27}$$

Solving forward, we get an analytical expressions describing their inflation and unemployment gap expectations for all future horizons in terms of their beliefs $\kappa_{t|t}, \xi_{t|t}^p, \pi_t^{*P}, \lambda_t^P$ formed conditional on $\mathcal{H}^t$:

$$E_t^P \pi_{t+j} = \underbrace{\pi_t^{*P}}_{\text{perceived target}} + \underbrace{\frac{\lambda_t^P}{\lambda_t^P(1-\rho) + \kappa_{t|t}^2}\rho^j \xi_{t|t}^p}_{\text{cost-push inflation}} \tag{28}$$

$$E_t^P x_{t+j} = \frac{\kappa_{t|t}}{\lambda_t^P(1-\rho) + \kappa_{t|t}^2}\rho^j \xi_{t|t}^p \tag{29}$$

Their expectations reflect simple economic intuition. According to Equation 28, from the private-agents' perspective, the path of inflation is ultimately determined by two forces: (i) π_t^{*P}, representing their beliefs about the central bank's inflation target, defines the level that the agents

[11] The expression $\frac{\kappa_{t|t}}{\lambda_t + \kappa_{t|t}^2}$ is bounded above by $\frac{1}{2\sqrt{\lambda_t}}$. So even though it also depends on κ_t, its limiting behavior is determined by λ_t.

expect inflation to converge to in the long run. Inflation expectations at all horizons move one-for-one with π_t^{*P}. Hence this belief is a crucial determinant of the low-frequency (slow-moving) dynamics of inflation; and (ii) persistent supply shocks $\xi_{t|t}^p$, which create involuntary inflation above and beyond this voluntary level in the short-run: the extent of their *pass-through* to short-run inflation expectations is *decreasing* in the perceived slope of the Phillips curve $\kappa_{t|t}$ but *increasing* in λ_t^P, the perceived weight that the central bank puts on unemployment-gap stabilization. Thus, when agents perceive the central bank to prioritize real-side stabilization (λ_t^P is large), their short-run inflation expectations respond to persistent supply shocks strongly and causes them to depart further away from the long-run level, π_t^{*P}.

Perceived policy rule: The interest-rate i_{t+1}^* that implements the optimal unemployment gap plan is given by the IS-curve:

$$i_{t+1}^* = \tau^{-1}(x_{t+1|t} - E_t^{P-} x_{t+2}) + E_t^{P-} \pi_{t+2} + r_{t+1|t}^n$$

where the private agents' ex-ante period-t expectations $E_t^{P-}\pi_{t+j}$ and $E_t^{P-}x_{t+j}$ are given by:

$$E_t^{P-}\pi_{t+j} = \pi_{t-1}^{*P} + \frac{\lambda_{t-1}^P}{\lambda_{t-1}^P(1-\rho) + \kappa_{t|t}^2}\rho^j \xi_{t|t}^p$$

$$E_t^{P-}x_{t+j} = \frac{\kappa_{t|t}}{\lambda_{t-1}^P(1-\rho) + \kappa_{t|t}^2}\rho^j \xi_{t|t}^p$$

4.3 Monetary policy surprises

The agents assume that the central bank sets interest rates optimally every period up to some idiosyncratic policy error of constant variance so that[12]:

$$i_{t+1} = i_{t+1}^* + \epsilon_t^i, \quad \epsilon_t^i \sim N(0, \sigma_i^2)$$

Whenever the nominal interest rate that the central bank sets is different from what the private agents expect-given their beliefs about prevailing macroeconomic conditions—it constitutes a

[12]The source of this error could be motivated as coming from cognitive noise in decision-making. It could also be thought of as a "control error". The main idea being that the private agents allow for idiosyncratic deviations from optimal policy arising from factors unrelated to changes in the policymakers' stabilization preferences.

monetary policy surprise:

$$\underbrace{i_{t+1} - E^P[i_{t+1}|\mathcal{H}^{t-1}, z_t]}_{\text{monetary policy surprise}} = \underbrace{(i^*_{t+1} - E^P[i_{t+1}|\mathcal{H}^{t-1}, z_t])}_{\text{agents behind the curve}} + \underbrace{\epsilon^i_t}_{\text{policymakers behind the curve}}$$

where $\mathcal{H}^{t-1}$ represents the history of all observed signals up to $t-1$, and z_t captures the current period realizations of inflation and unemployment rate.

Agents interpret policy surprises as stemming from two sources: an evolution in policymakers' preferences, which they must learn about ('agents behind the curve'), or a transitory policy error, which policymakers must subsequently correct ('policymakers behind the curve').

From the IS-curve and the optimal unemployment gap plan, we obtain the following expression mapping the policymakers' period-t preferences to the optimal nominal interest rate:

$$i^*_{t+1}(\pi^*_t, \lambda_t) = \underbrace{-\tau^{-1}E^{P-}_t x_{t+2} + r^n_{t|t} + E^{P-}_t \pi_{t+2}}_{\text{ex-ante known}} + \underbrace{\frac{\tau^{-1}\kappa_{t|t}}{\lambda_t + \kappa^2_{t|t}}(E^{P-}_t \pi_{t+2} + \rho\xi^p_{t|t} - \pi^*_t)}_{\text{contains information about Fed objectives}}$$

When the central bank sets interest rates, it reveals information regarding its policy preferences. The second term represents the only component of systematic monetary policy that contains information regarding the "true" period-t policy preferences π^*_t and λ_t. Observe that as λ_t increases, the term carrying information regarding the policymakers' stabilization preferences shrinks.

In the limiting case of $\lambda_t \to \infty$, this term shrinks to zero and interest rates carry no information: the "learning channel" of policy completely dies out. When agents perceive the central bank to have such preferences, they expect the unemployment gap to be zero at all future horizons and the central bank is seen to implement a Wicksellian policy: with the the ex-ante real interest rate $i^*_{t+1} - E^{P-}_t \pi_{t+2}$ tracking the perceived natural rate of interest $r^n_{t|t}$ closely. In this case, policymakers are expected to tolerate arbitrary deviations in inflation: there is no inflation-target and the level of inflation is indeterminate, leading to self-fulfilling dynamics. On the other hand, when $\lambda^P_t \to 0$, agents' always expect the central bank to bring inflation back to its target π^*_t regardless of the unemployment gap costs. Hence their inflation expectations at all horizons are equal to the perceived inflation target, irrespective of supply shocks $\xi^p_{t|t}$. Policy is seen oriented only towards keeping inflation close to target. Interest rates provide a strong signal regarding the inflation target. Note that policy response to $E^{P-}_t x_{t+2}$ and $r^n_{t|t}$ does not depend on

λ_t - since they don't pose a policy trade-off (often referred to as the "divine coincidence").

4.4 The nonlinear filter

The observed nominal interest rate functions as a noisy signal about the central bank's preferences $[\pi_t^*, \lambda_t]$, which describe the relevant state that the agents learn about:

$$i_{t+1} = i^*_{t+1}(\pi_t^*, \lambda_t) + \epsilon_t^i, \quad \epsilon_t^i \sim N(0, \sigma_i^2)$$

Linearizing around agents' prior estimates $\pi_{t-1}^P, \lambda_{t-1}^P$ assuming $\pi_t^* \approx \pi_{t-1}^P, \lambda_t \approx \lambda_{t-1}^P$[13]

$$i^*_{t+1}(\pi_t^*, \lambda_t) \approx i^*_{t+1}(\pi_{t-1}^{*P}, \lambda_{t-1}^P) + \frac{\partial i^*_{t+1}}{\partial \pi_t^*}|_{\pi_{t-1}^{*P}, \lambda_{t-1}^P}(\pi_t^* - \pi_{t-1}^{*P}) + \frac{\partial i^*_{t+1}}{\partial \lambda_t}|_{\pi_{t-1}^{*P}, \lambda_{t-1}^P}(\lambda_t - \lambda_{t-1}^P)$$

The approximation above (called the Extended Kalman Filter) yields an expression for i^*_{t+1} that is linear in the latent states π_t^* and λ_t much like the simple Kalman filter. The key difference is that the coefficients mapping the observable i^*_{t+1} to the latent states are not constant, but state-dependent. They are determined by the partial derivatives of the interest rate rule with respect to the π_t^* and λ_t evaluated at the agents' prior estimates π_{t-1}^{*P} and λ_{t-1}^P. These determine how "informative" interest rates are perceived to be regarding the underlying stabilization preferences of the policymakers.

The agents perceive that $\log \pi_t^*$ and $\log \lambda_t$ evolve exogenously as independent random walks, so that:

$$\begin{pmatrix} \log\ \pi_t^* \\ \log\ \lambda_t \end{pmatrix} = \begin{pmatrix} \log\ \pi_{t-1}^* \\ \log\ \lambda_{t-1} \end{pmatrix} + \begin{pmatrix} \epsilon_t^{\pi^*} \\ \epsilon_t^{\lambda} \end{pmatrix}, \qquad \begin{pmatrix} \epsilon_t^{\pi^*} \\ \epsilon_t^{\lambda} \end{pmatrix} \sim N(\mathbf{0}, \begin{pmatrix} \sigma_{\pi^*}^2 & 0 \\ 0 & \sigma_\lambda^2 \end{pmatrix})$$

Every period, agents update their beliefs π_t^{*P} and λ_t^P based on their best-estimates as:

$$\pi_t^{*P} = \pi^*_{t|t}, \quad \lambda_t^P = \lambda_{t|t}$$

[13]This assumption is important for the filtering problem to be well-specified. Since interest-rate dynamics would be state-dependent due to the nonlinearity of i^*_{t+1}, large discrepancies can cause the filter to diverge. The assumption implicitly implies that under their own beliefs, agents track changes in the policymakers' preferences efficiently at all times. In subsection F.2, I report evidence in support of this assumption based on the Fed's Greenbook forecasts.

4.5 What anchors long-run beliefs?

Anchoring reflects the entrenchment of expectations, where beliefs about the future remain resilient to surprises. The following quote by Ben Bernanke summarizes what anchoring means in the context of monetary policy:

> "...I use the term "anchored" to mean relatively insensitive to incoming data. So, for example, if the public experiences a spell of inflation higher than their long-run expectation, but their long-run expectation of inflation changes little as a result, then inflation expectations are well anchored..." —Bernanke (2007)

According to Equation 28, agents' long-run inflation expectations are completely pinned down by their beliefs regarding the central bank's inflation target. For inflation expectations to be "well-anchored" according to this definition, agents should not revise their beliefs regarding the target by much even as they anticipate inflation to remain elevated in the short-run on account of persistent supply shocks. In the model, revisions to agents' long-run inflation expectations occur only in response to interest rate surprises. The degree of *pass-through* from these surprises to their perceived inflation target depends on how informative they perceive policy actions to be, about the underlying shifts in the central bank's inflation objective π_t^*.

Anchoring is state-dependent

The perceived informativeness of the observed interest rate signal about the states π_t^* and λ_t is described by the Jacobian (first-order partial derivatives) of the interest-rate rule with respect to these state variables, evaluated at their ex-ante beliefs π_{t-1}^{*P} and λ_{t-1}^P:

$$\frac{\partial i_{t+1}^*}{\partial \pi_t^*}|_{(\pi_{t-1}^{*P}\lambda_{t-1}^P)} = -\frac{\tau^{-1}\kappa_{t|t}}{\lambda_{t-1}^P + \kappa_{t|t}^2} \tag{30}$$

$$\frac{\partial i_{t+1}^*}{\partial \lambda_t}|_{(\pi_{t-1}^{*P},t\lambda_{t-1}^P)} = -\frac{\tau^{-1}\kappa_{t|t}}{(\lambda_{t-1}^P + \kappa_{t|t}^2)[\lambda_{t-1}^P(1-\rho) + \kappa_{t|t}^2]}\rho\xi_{t|t}^P \tag{31}$$

Naturally, if the Jacobian with respect to a particular state variable is of large magnitude, interest rates are perceived to be highly responsive to changes in that state and hence, agents put more weight on the signal while updating their beliefs.

Equation 30 implies that interest rates fall in response to an increase in the policymakers' inflation target. Thus when interest rates undershoot expectations, agents respond by revising their beliefs regarding the inflation target upwards. However, the magnitude of the updates would be decreasing in λ^P_{t-1}. The magnitude of the term $\frac{\kappa_{t|t}}{\lambda^P_{t-1}+\kappa^2_{t|t}}$ is an important determinant of the degree of anchoring of long-run inflation expectations since they determine how much weight the agents put on a given interest rate surprise and revise their beliefs about the inflation target. Hence, I call its reciprocal the "anchoring coefficient" (large value corresponds to more anchored long-run inflation expectations). When this term is large, long-run expectations remain more firmly "anchored". λ_t may also be interpreted as policymakers' adherence to the natural-rate theory under which they treat departures of the unemployment rate from its natural rate as costly. A smaller value of λ_t implies that the natural rate of unemployment is less relevant to policy design.

According to Equation 31, the degree to which interest rates respond to supply shocks is decreasing in λ_t. If interest rates are seen to rise more strongly in response to a persistent supply shock than the agents expect based on their ex-ante beliefs, they infer that λ_t is smaller and their beliefs λ^P_t get revised downward. Note that λ_t is irrelevant to policy in the absence of policy trade-offs and hence meaningful updates to λ^P_t only occur when agents perceive their economic environment to be characterized by persistent supply shocks posing such trade-offs.

5 Estimation

To characterize the path of beliefs and expectations, we must pin down the vector of parameters:

$$\Phi = [\tau, g_u, \sigma^2_{\xi,P}/\sigma^2_{\xi,T}, \sigma^2_i, \sigma^2_{\pi^*}, \sigma^2_\lambda]$$

These parameters govern how private agents update beliefs in equilibrium conditional on their observations. Given a vector of parameters Φ and a history of realizations $\mathcal{H}^t$, the path of private-sector beliefs regarding the state variables $\{\kappa_t, \xi^P_t, u^n_t, r^n_t\}$ as well as the central bank's policy preferences $\{\pi^*_t, \lambda_t\}$ are determined under the learning scheme described in the previous sections.

I set the parameter ρ governing the persistence of the persistent component of the supply shocks as perceived by the agents to 0.99, so that it is meaningfully distinct from the transitory i.i.d component so that it doesn't pose identification problems. It also captures a particularly low-frequency component of the supply shocks which would be the most relevant for forming expectations.

5.1 Data

The learning algorithm is implemented with monthly data on Headline CPI Inflation (CPIAUCSL), Unemployment rate (UNRATE) and the Effective Fed Funds rate (FEDFUNDS) from 1958:01-2024:12 (available from FRED St Louis) as observations. For the zero-lower bound period, the Wu-Xia shadow interest rate is used as the measure of the nominal interest rate instead of the effective Fed funds rate. The initial beliefs are set to have large variance in order to allow them to adjust freely in response to data. I allow 48 periods (4 years) for the filter to converge to steady-state and the estimates from this period are discarded.

To estimate the vector of parameters governing learning, Φ, I use survey data on long-run inflation expectations from the Survey of Professional Forecasters (SPF)—specifically, the cross-sectional mean of the 10-year-ahead CPI inflation forecasts—as a proxy for private agents' beliefs about the Federal Reserve's inflation target.[14] The SPF series is available at a quarterly frequency over the period 1991–2024. The implicit assumption here is that professional forecasters' long-run inflation expectations are broadly representative of those held by firms and households. Given the low volatility of long-run inflation expectations during this period, this assumption is reasonable: discrepancies between types are unlikely to be large.

Although alternative measures covering a longer sample period exist such as the Michigan Survey of Consumers and Cleveland Fed's 10-year ahead inflation expectations series[15], they are not used in the baseline estimation. However, they are employed in an out-of-sample validation test (see Appendix A) to assess the robustness of the results. Not explicitly including long-run inflation expectations data for the Great Inflation period allows us to check if the structural dynamics captured by the model can provide a consistent explanation for their behavior during this period without explicitly being fit to the data.

5.2 Estimation results

The goal of estimation is to pin down the vector Φ that generates a path of long-run expectations closest to the observed survey measure under the agents' learning mechanism given their observations. A least-squares minimum-distance estimator is used, matching the path of model-implied private-sector beliefs regarding the inflation target π_t^{*P} with the observations from the

[14] Short-run inflation forecasts depend upon a combination of π_t^{*P}, λ_t^P and $\xi_{t|t}^p$, which makes these parameters harder to identify if those are used for estimation. Long-run inflation expectations have the advantage that they isolate movements due π_t^{*P} alone as beliefs regarding the other parameters play a negligible role at longer horizons.

[15]

SPF. The minimum-distance estimate Φ^* is the solution of the resulting minimization problem:

$$\Phi^* = \underset{\Phi}{\text{argmin}} \sum_{t=1991:01}^{2024:12} ([\pi_t^{*P}|\mathcal{H}^t, \Phi] - \pi_t^{10y,SPF})^2$$

I discard values of Φ that generate explosive paths for beliefs. This problem arises because beliefs are a non-differentiable function of Φ: even small perturbations in the parameters can induce large changes in the updating process across all variables, setting off some beliefs on divergent paths.[16]

The point-estimate of Φ^* along with 95% credibility intervals generated using Sequential Monte Carlo (SMC) sampling are shown in Table 1. The point-estimate implies that the variance of innovations in the policy preference parameters is very small compared with the idiosyncratic policy errors. The innovations to persistent cost-push shocks are also approximately 10^3 times smaller than i.i.d. innovations.

Appendix B compares the agents' ex-ante forecasts of inflation, unemployment rate and the nominal interest rate informed by their model with the actual realizations to assess the fit. The agents' perceived model is able to track the target variables closely and learning performs satisfactorily in the sense of making small forecast errors.

[16]This also makes the use of gradient-based optimization algorithms infeasible. I use the Nelder-Mead direct search method that does not require the computation of gradients or derivatives of the objective function.

Table 1: Estimated parameters of the baseline model

Parameter	**Description**	**Estimate (95% CI)**
τ	Ratio of IES to Okun's law coefficient	$0.647\ (0.430,\ 1.184)$
g_u	Gain for updating u_t^n	$0.329\ (0.209,\ 0.351)$
σ_i^2	Variance of idiosyncratic monetary policy errors	$0.488\ (0.389,\ 1.334)$
$\sigma_{\pi^*}^2$	Variance of innovations to (log)inflation target	$6.696\ (5.186,\ 7.772) \times 10^{-4}$
σ_λ^2	Variance of innovations to (log)weight on unemployment-stabilization	$6.802\ (3.611,\ 9.173) \times 10^{-5}$
$\frac{\sigma_{\varepsilon^t}^2}{\sigma_{\varepsilon^p}^2}$	Ratio of the variance of innovations to the transitory component of cost-push shocks to that of the persistent component	$911.901\ (196.125,\ 5176.436)$

Note: Confidence intervals are constructed using Sequential Monte Carlo sampling. The likelihood function is not differentiable in the parameters Φ, so asymptotic standard errors cannot be used.

6 Evolution of the agents' beliefs

This section discusses time-paths of private-sector agents' beliefs regarding the structural variables describing the economy as implied by the point estimates given in Table 1. The section also provides context on how beliefs evolved and their bearing on the macroeconomic outcomes in the post-war period.

6.1 The Fed's inflation target

Figure 2 illustrates the model-implied path of the agents' perceptions regarding the Fed's inflation target. This is in contrast with papers such as Bhattarai, Lee and Park (2016) that rely on identifying the inflation target from low-frequency movements in inflation.

According to the model, the private agents perceive the Fed's inflation target to be close to 2% in the early 1960s. In the latter half of the decade, the perceived target begins to rise, reaching around 4% by 1970.[17]

[17] Hence I find that the anchor had begun to loosen in the late 1960s, before the appointment of Arthur Burns (in

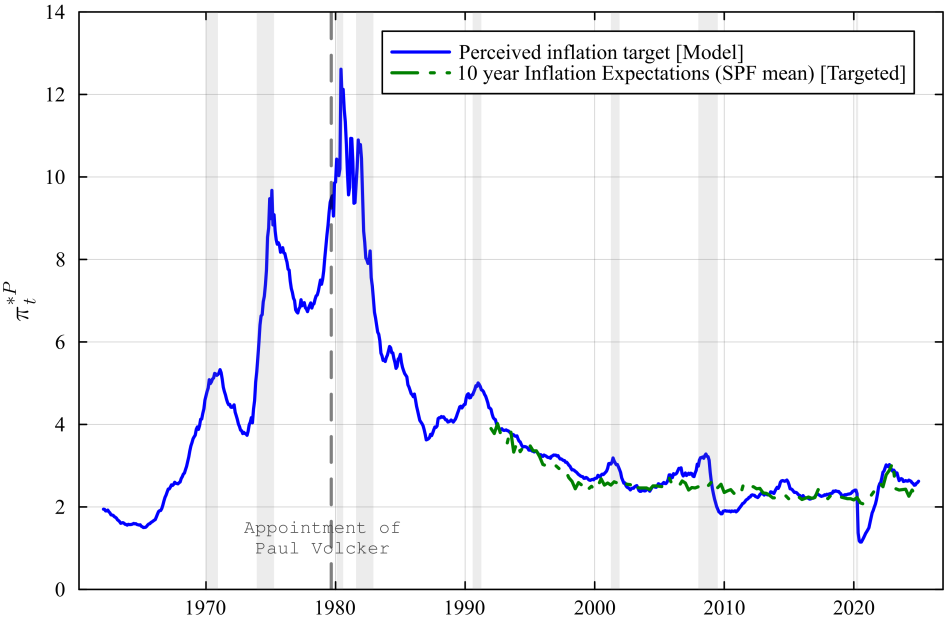

Figure 2: **Perception of the Fed's inflation target**

Note: Private agents' beliefs regarding the Fed's inflation target as implied by the model (π_t^{*P}) *(solid)* vs SPF 10-year inflation expectations *(dashed)* which serves as the empirical proxy. During the Great inflation, private-sector beliefs about the inflation target exhibit sharp upward revisions. This is not the case during the recent surge. The shaded regions indicate NBER recessions. The SPF 10-year ahead inflation expectations series begins in 1991:Q1 and is obtained from the Philadelphia Fed website.

From the eyes of the private sector, the 70s would be a period of great volatility in the Fed's inflation target. Their beliefs are sharply revised upwards on two occasions, each coinciding with an NBER recession—one during the beginning of the decade and the other around the time of the OPEC Embargo and the oil crisis of 1974. From the lens of the model, the private agents saw that the Fed had an *incentive* to inflate the economy, over and beyond any supply disturbances creating policy trade-offs. From their point of view, the Fed displayed a tendency to deliberately inflate the economy during recessions, operating with a higher inflation target, followed by dis-inflationary pursuits soon after. The Volcker-era, beginning with the chairmanship of Paul Volcker in 1979 is often cited as watershed moment in the Fed's eventual "conquest" of inflation. In October 1979, the Fed announced "new operating procedures" aimed at reining in inflation. But these do not immediately effect a disinflation (as also noted by Goodfriend and King (2005)). A recession follows and the perceived target shoots up yet again. It is not until 1982 that we see the perverse dynamics reverse course. The following years see a sharp decline in the perceived inflation target which coincides with a deep recession. By the mid 1980s, agents perceive the Fed's inflation target to be below 5% after nearly a decade. Thus the

1970), similar to Reis (2021). In December 1965 a policy-tightening provoked an unprecedented backlash against Fed Chair Martin, marking what many observers regard as the beginning of a prolonged era of accommodative monetary policy.

U.S. economy enters the “Great Moderation”. Beliefs regarding the Fed’s target are on a steady downward trajectory in the two decades that follow, under the chairmanship of Alan Greenspan (1987-2006). Only during the Great Financial crisis and the recent COVID-pandemic do we see the agents’ perceptions exhibiting some modest revisions (interestingly, breaking away from the SPF series).

The model implies a modest uptick in the agents’ perceptions regarding the Fed’s inflation target during the post-pandemic episode, also observed in the SPF data, showing that there was some endogenous feedback from monetary policy in the post-pandemic period to private agents’ long-run inflation expectations. Yet, beliefs about the target only rise to about 3%. This is remarkable considering that CPI inflation itself reached a peak of 9.1% in June 2022. The same learning mechanism that caused agents to anticipate inflation to remain put at levels as high as 11% during the 80s, told them that inflation was on course to settling around 3% - the inflation crisis left their long-run beliefs more or less unchallenged.

Figure 3 further illustrates how the link between realized inflation and long-run inflation expectations has weakened following the Volcker disinflation. Upto the mid-1980s, the perceived inflation target moved closely with actual inflation. Afterwards however, while CPI inflation continued to fluctuate, agents’ beliefs about the target moved very slowly. In the mid-1980s, even as inflation fell below 2.5% for the first time in nearly two decades, the perceived target hovered near 4%. Hence, for a time, agents viewed the benign inflation as a temporary reprieve driven by the macroeconomic environment soon to be undone by policy.

While I argue that the conduct of policy created the perception among private agents that the inflation target had risen substantially during the 1970s, the model does not take a stand on what would cause the policymakers to acquire a taste for such exorbitant levels of inflation. Narrative evidence offered by Romer and Romer (2002), DeLong (1996) provide some valuable clues: inflation was deliberately pursued under the false notion that unemployment could be driven lower by inflationary surprises. This behavior would be broadly consistent with the policymakers’ implied target rising during recessions. Under this explanation, the policymakers did not view the natural rate of unemployment as a constraint on policy design, instead viewing the Phillips curve as offering an exploitable long-run trade-off between inflation and unemployment. The results in the next subsection are consistent with the idea that the conduct of policy had signaled little concern for keeping the unemployment gap closed during this episode.

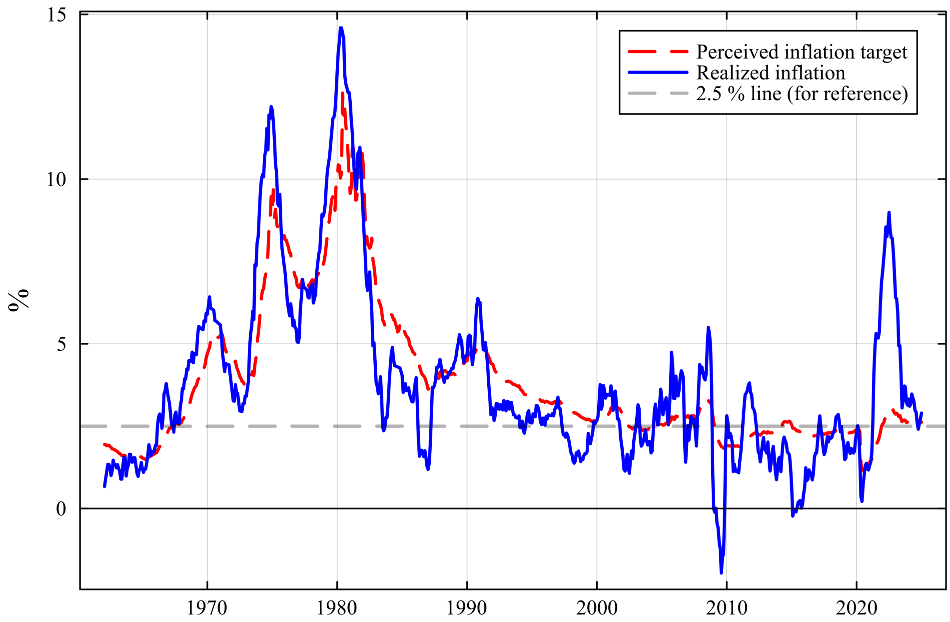

Figure 3: **Weakening link between realized inflation and long-run expectations**

Note: Realized CPI inflation *(solid)* vs Model-implied private-sector beliefs about the inflation target *(dashed)*. Co-movement between current CPI Inflation and the private-sector's beliefs regarding the long-run inflation target has weakened considerably since the Volcker disinflation.

6.2 The Fed's weight on unemployment gap stabilization

Figure 4 plots the evolution of the private sector's estimates of λ_t: the relative weight the Fed puts on closing the unemployment-gap. The estimates suggest that, during the early 1960s, the private sector attributed relatively little concern from the Fed towards closing the gap.

After a slow and steady rise following the Volcker disinflation, perceptions regarding λ were sharply revised upwards following the Global Financial Crisis and again in the aftermath of the COVID-19 pandemic: the emphasis of policy has shifted. This development has had important implications for the anchoring of expectations. Concisely, a large λ implies that the Fed "ties its hands"; unemployment gaps are perceived as costly and hence policy emphasizes keeping the gap closed - policy behavior that is conducive to the stability of inflation in the long-run. A large λ_t also has the effect of making future unemployment gaps more predictable (since they are closer to zero) and less responsive to supply shocks, ultimately reducing real-side volatility.

These findings are consistent with recent empirical literature using high-frequency identification utilizing changes in asset prices around Fed policy announcements to study how the private sector learns about the Fed's "policy rule" (e.g., Bauer and Swanson (2023), Bauer, Pflueger and Sunderam (2024), Pflueger (2025)). These studies find that monetary policy in the recent period, following 2000, has been perceived to be increasingly responsive to output. A rise in λ_t, and the greater predictability of unemployment-gaps also complements earlier findings that output-gap volatility in the U.S. has declined significantly since the Volcker disinflation (see Blanchard and Simon (2001); McConnell and Perez-Quiros (2000)), underscoring the role of systematic monetary policy in engineering output-stability.

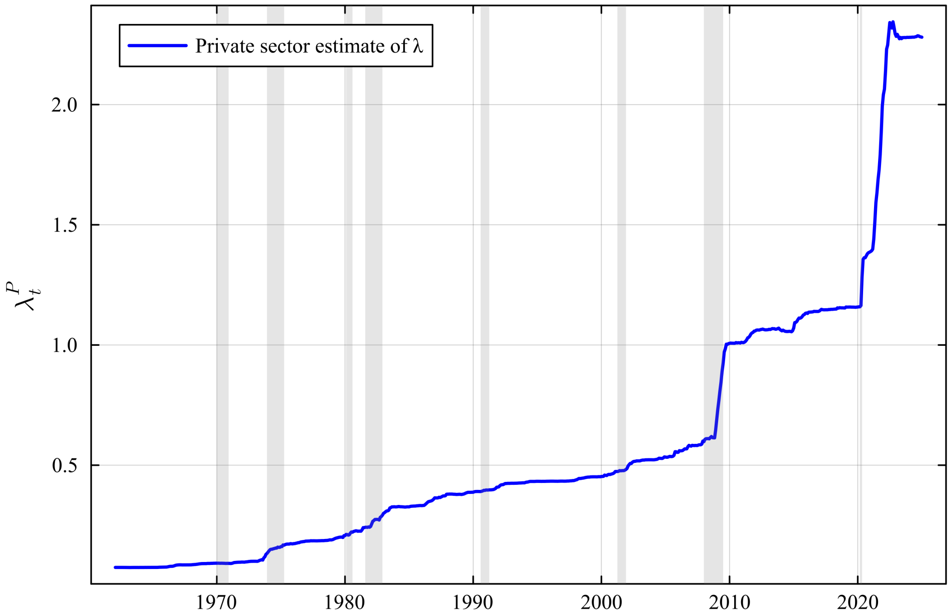

Figure 4: **Perception of the Fed's weight on unemployment-gap stabilization**

Note: Evolution of the Private sector estimate of λ_t. The private sector perceives the Fed to put more emphasis on stabilizing the unemployment-gap. The shaded regions indicate NBER recessions

6.3 The slope of the expectations-augmented Phillips Curve

The parameter κ, represents the sensitivity of aggregate inflation to contemporaneous unemployment gap. Hence, it serves as the connective tissue between the real and nominal side of the economy and is a key parameter that agents must learn. Figure 5 plots the evolution of the agents' beliefs regarding the slope of the expectational Phillips curve under their learning mechanism. Under the agents' prior, κ is time-invariant. However, their real-time estimates under learning exhibit significant time-variation over the sample period.

Since κ is not subject to innovations, the steady-state filter would be a decreasing-gain one. As new data is observed and beliefs are updated, each additional observation carries marginally less information and their beliefs should stabilize near a constant value. But it does not appear that any such convergence has attained within the sample period spanning about 60 years.

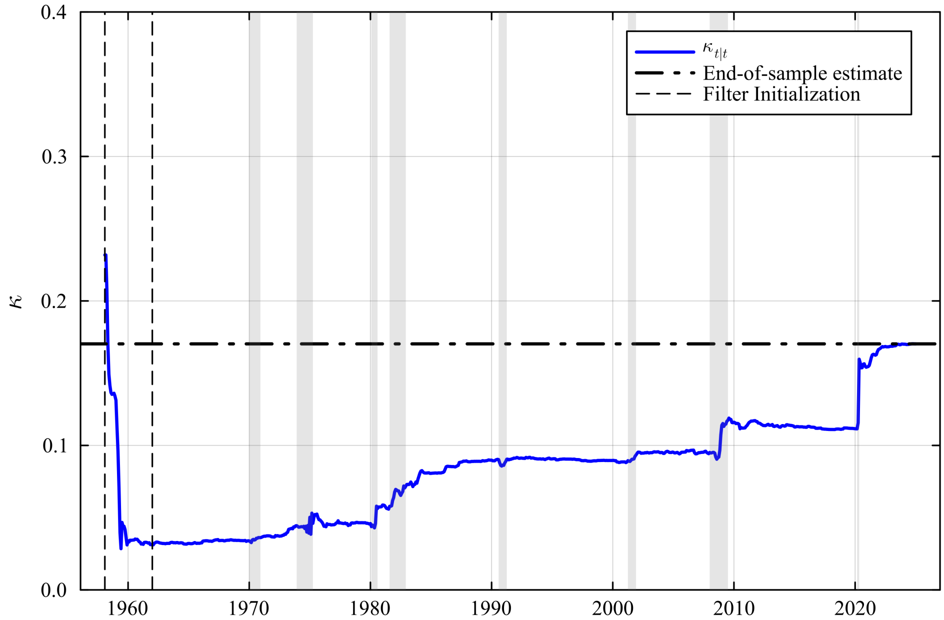

Figure 5: **Slope of the expectations-augmented Phillips curve**

Note: The figure plots the filtered estimates of the slope of the Phillips curve (*solid line*). From the private agents' perspective, the Phillips curve is steeper now than it was during the Great Inflation period. Even though the agents learn under the assumption that the true structural Phillips curve has a time-invariant slope, their beliefs are subject to constant revisions owing to the identification problems posed by the information structure of the economy. The shaded regions indicate NBER recessions

To understand why this is the case, let's revisit the observation equation through which agents update their beliefs regarding κ and ξ_t^p:

$$\pi_t - E_{t-1}^P \pi_{t+1} = -\kappa x_t + \xi_t^p + \xi_t^t$$

Note that current inflation, π_t delivers information about κ only through the unemployment gap x_t. It is not surprising then, that we see the bulk of the large updates in agents' estimates of κ around recessions (corresponding to large variations in x_t). During "normal" times, the unemployment gap is small and it is hence evident that learning would slow down (since inflation carries little information regarding the true κ). In totality, the signal informing the agents about κ gets drowned out due to (i) the unemployment gap x_t being of small magnitude most of the time (Figure 14 in Appendix D plots the evolution of the variable) and (ii) the presence of cost-push shocks confounding the estimation. The second of these reasons is a familiar one: Supply shocks are known to confound the estimation of the Phillips curve and the literature has often relied on adding oil prices or similar variables as proxies. Inferring the slope of the structural Phillips curve has been among the most enduring and difficult problems in macroeconomics. It is hence no surprise that the agents in the model are not immune to the fundamental econometric challenges that it poses. Models assuming full-information mask such issues entirely.

The agents perceive the slope to be relatively "flat" during the 1970s. This belief would be reinforced by the experience of high inflation in the face of rising unemployment experienced during this period. The perception of a flat Phillips curve is one of the primary reasons cited by Primiceri (2006) and Sargent, Williams and Zha (2006) for the policymakers' aversion to act decisively against inflation during this period. The agents revise their beliefs over time and see the slope become steeper over time.[18] In the post-pandemic period, the large decline in inflation from its highs with little rise in unemployment leads the agents to update their beliefs about κ upwards. Overall, the results suggest that real-time identification of the Phillips curve is quite poor and agents' estimates would take an unreasonably long time to converge to a constant.

However, estimates during the entire sample period remain within a plausible range (between 0.05-0.20) and the model does not need to rely on an excessively flat Phillips curve to rationalize the outcomes of the past 20 years. The estimates also shine a light on why recent literature has invoked specifications involving a nonlinear Phillips curve to explain the behavior of inflation during the post-pandemic surge (see Harding, Lindé and Trabandt (2023) Benigno and Eggertsson (2024))[19]. Though the model considered here does not nest such nonlinearities, agents' perceptions regarding the true slope do change substantially during the pandemic-recession. They perceive the slope to be much steeper now. Whether this represents a change in the true underlying structural slope is yet an open question outside the scope of this paper.

6.4 Anchoring Coefficient

In subsection 4.5, we derived a quantity measuring the responsiveness of interest rates to changes in the target and denoted its reciprocal as the "anchoring coefficient", $\zeta_t = \frac{\lambda^P_{t-1}+\kappa^2_{t|t}}{\kappa_{t|t}}$. I plot the evolution of ζ_t in Figure 6.

From the private agents' vantage point, the policy environment has changed drastically in the 40 years separating the Great Inflation and the post-pandemic surge. The degree of anchoring

[18]This is in contrast with the literature finding a flattening Phillips curve over time. However, the estimates are not directly comparable to the one here since the empirical specification used is very different.

[19]However, Beaudry, Hou and Portier (2025)) find limited evidence in favor of nonlinear Phillips curve specifications once inflation expectations are explicitly taken into account.

of long-run inflation expectations has steadily increased over the past 40 years - even more so since the GFC and the pandemic. According to the model, long-run inflation expectations are more entrenched at this juncture than any other time in the post-war history of the United States. This yielded in large part due to the steady increase in λ_t over this period. The rise in this coefficient is precisely what gave the Fed room to continue to "look-through" supply shocks, adopting a wait-and-see approach without triggering large revisions in the perceived inflation target. Beliefs about the inflation target are quite unresponsive to interest rates. While this makes de-anchoring due to perceived mistakes unlikely, it also hampers the Fed's ability to guide these beliefs back to target *if* they were to change. An implication of the model is that the steadfast disinflation of the 80s would be much less likely given the circumstances now.

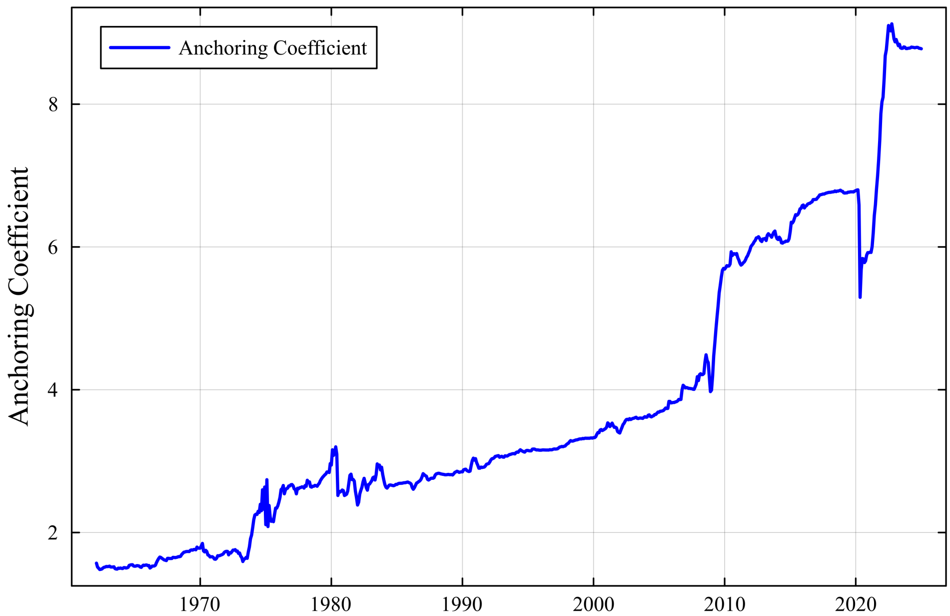

Figure 6: **Evolution of the anchoring coefficient** ($\frac{\lambda^P_{t-1}+\kappa^2_{t|t}}{\kappa_{t|t}}$)

Note: The coefficient measuring the "anchoring" of long-run inflation expectations has risen drastically. Even as the perceived slope of the Phillips curve has risen, the rise in the perceived weight on unemployment gap stabilization λ^P_t has outpaced it and made the coefficient larger.

6.5 "Bad luck" vs "bad policy" revisited

The following section contributes to the debate regarding whether the economic outcomes of the post-Volcker period were a result of luck (favorable economic environment, benign shocks) or systematic policy (shifts in the Fed's implied policy objectives). I discuss how evolving perceptions regarding structural shocks and the Fed's systematic monetary policy contributed to shaping macroeconomic outcomes in the post-war period in the U.S.

6.5.1 The role of policy in shaping agents' expectations

To assess the role of the Fed's systematic monetary policy, it is useful to consider the perceived real rate gap, defined as the difference between the ex-ante real interest rate and the perceived natural rate of interest, $r^n_{t|t}$. A positive real rate gap implies that the policy exerts upwards pressure on the unemployment gap and thereby indicating a contractionary policy stance. Conversely, a negative real rate gap reflects an expansionary stance of policy.

Figure 7 illustrates agents' perceptions of the real rate gap and the persistent supply shocks in the economy. As we can see, the late 60s are characterized by moderate supply shocks. But the real rate gap tends to stay negative throughout the latter half of the decade.[20] The mid 1970s see an escalation with mounting supply shocks and an ever-expansionary policy stance by the Fed. Since policy was seen as tolerant of creating real disturbances to achieve its inflation goals, the only natural explanation was a higher inflation target. Long-run inflation expectations shot up.

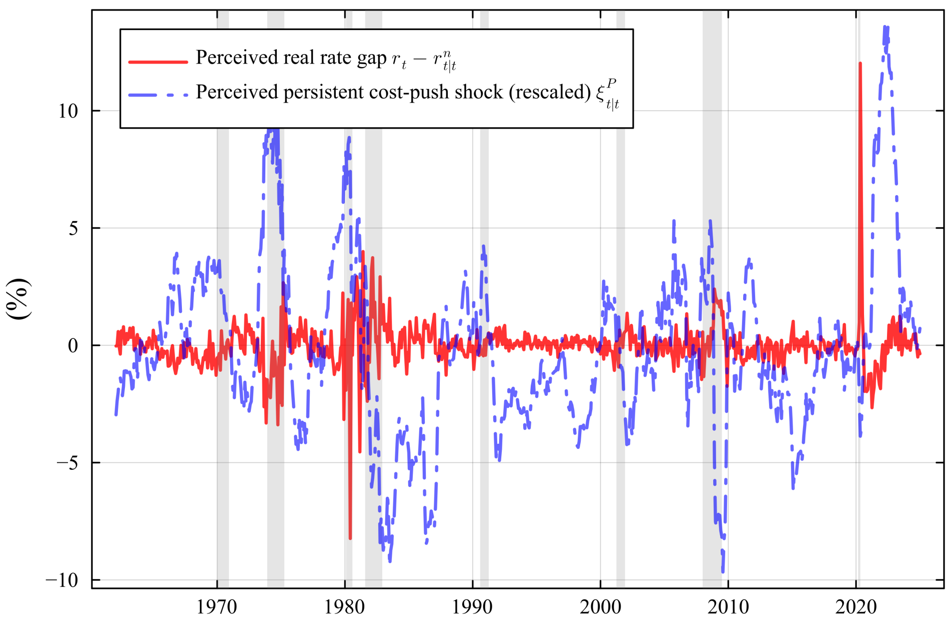

Figure 7: **Policy response to inflationary shocks:**

Note: The perceived real rate gap $r_t - r^n_{t|t}$ *(solid)* vs filtered estimates of persistent supply shocks $\xi^p_{t|t}$ *(dashed)*. We can see that supply-side pressures in the 70s and 80s were met with accommodative policy by the Fed. Policy was perceived to be similarly accommodative at the beginning of the post-pandemic surge. The shaded regions indicate NBER recessions

"Forever inflation" took hold with no resolve from policymakers to combat it. It is not until 1980,

[20]Some narrative evidence from this period finds that Chairman Martin's initial anti-inflation stance clashed with expansionary fiscal policy by the Congress. This ended up eroding the postwar monetary discipline of the Fed, with focus shifting from inflation stabilization to policy accommodation.

under the chairmanship of Paul Volcker that we see a sustained positive real rate gap leading to the eventual “conquest over inflation”. From the model’s perspective, two aspects of policy behavior in the post-Volcker period were important for the onset of the “Great Moderation”: (i) a positive real rate gap was maintained for a prolonged period signaling a lower inflation target and (ii) muted response of policy to persistent shocks in the Phillips curve signaling a steadily increasing weight on real-side stabilization represented by λ_t. These gradually led the agents to believe in a low, stable inflation target. Note that without (ii), the anchoring would be fragile and long-run beliefs would have been similarly volatile, shooting up at any hint that Fed policy was “too loose”.

Turning to the post-pandemic period, the agents see the mistakes of the 70s being repeated: persistent supply shocks re-emerge and the Fed is nowhere close to contain the imminent crisis. Yet, we see long-run inflation expectations remain largely stable. This time however, after a period of “looking through” supply shocks, the Fed quickly catches up and the agents see the real-rate gap close. From the model’s perspective, even as the agents perceived the policymakers to be making a similar kind of mistake at the beginning during the recent surge, their expectations responded differently: in large part due to a change in their perceptions regarding λ_t - agents were slower to revise their beliefs about the inflation target despite the “mistake”. Disciplined Fed policy has shaped agents’ beliefs in a way that prevented the sudden inflationary spiral of the 70s despite a delayed policy response. Good policy of the past continues to bear fruit. Since the Fed acted decisively when it did and managed to raise the real rates above the perceived natural rate, it managed to signal that the inflation target was intact.

6.5.2 Supply shocks: The structural drivers of policy trade-offs

As the only variable driving a trade-off between inflation and unemployment gap stabilization, persistent supply shocks cause all “involuntary” inflation, over and beyond the Fed’s targeted level. Agents’ beliefs about these shocks are an important determinant of their short-run inflation expectations and hence of inflation dynamics themselves.

Figure 8 plots the time-series of the agents’ beliefs (real-time as well as smoothed) regarding persistent supply shocks in the Phillips curve. One fact that emerges is that the agents perceived large persistent supply shocks, both during the Great Inflation of the 70s-80s and in the more recent inflation surge. Moreover, the shocks were of roughly similar magnitude across the two episodes if not larger during the recent episode. Hence, the going by the size of the shocks alone, one would find it hard to explain why the inflation crisis was much more benign this time.

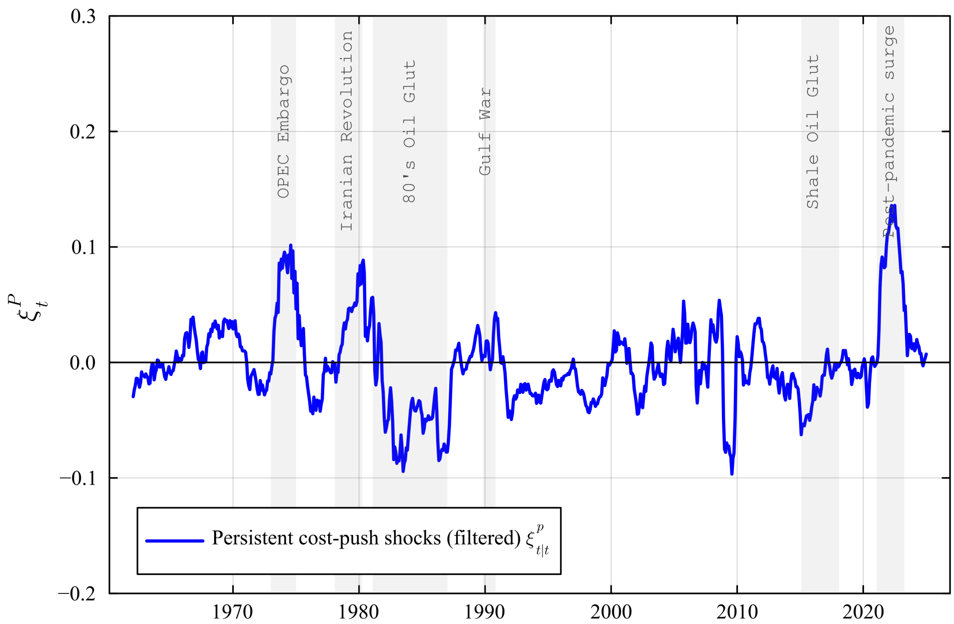

Figure 8: **Structural drivers of inflation**

Note: Private agents' estimates of the persistent component of the cost-push process ξ_t^P: Filtered *(solid)* vs smoothed *(dashed)* The magnitude of persistent cost-push shocks perceived by the agents during the post-COVID period were similar to those during the Great Inflation period. The shaded regions indicate known episodes of significant supply pressures.

The perceived supply shocks line up well with documented episodes of oil price surges. There is ample evidence in the literature that fluctuations in relative prices of energy goods are significant drivers of inflation (see Afrouzi, Bhattarai and Wu (2024), Gagliardone and Gertler (2023) for recent papers examining link between crude oil prices and the post-pandemic inflation surge). Interestingly, the last time that the agents perceived inflationary supply shocks was during the recovery from the Great Financial Crisis (GFC). This is consistent with evidence that oil price shocks in the aftermath of the crisis propped up inflation expectations accounting for the "missing deflation" (Coibion and Gorodnichenko (2015)). According to the model, even as the agents' long-run inflation expectations remain stable during this period, their short-run expectations are quite responsive to inflationary supply shocks during this period.

To aid interpretation of these "persistent supply shocks", in Figure 9 I plot the series against food and energy price inflation derived as the difference between Headline CPI and Core CPI. The series are de-meaned and re-scaled for comparison. The two series display significant co-movement. Since Core CPI is not a series that the model has "seen" (only Headline CPI data is used during estimation), it is remarkable that such a link emerges.

The post-pandemic episode was characterized by structural shifts over and above oil price surges, such as sectoral shocks shifting consumption between goods and services (see Guerrieri et al. (2021)) structural changes in the labor market (Blanchard and Bernanke (2023), Ball et al. (2022)), increasing attention to inflation (Pfauti (2023)) to name a few. However, shocks to relative food and energy prices appear to explain a large part of the variation in these persistent supply shocks perceived by the agents. This is intuitive considering how *salient* these prices are (as also argued by Coibion and Gorodnichenko (2015)). It makes sense that firms and households' perceptions about inflation in the short run would respond to these prices given their pervasive impact on the rest of the economy (as argued in Afrouzi et al. (2024) using a model of input-output linkages). Hence, the model adds support to the literature emphasizing the importance of relative price disturbances in driving aggregate inflation dynamics.

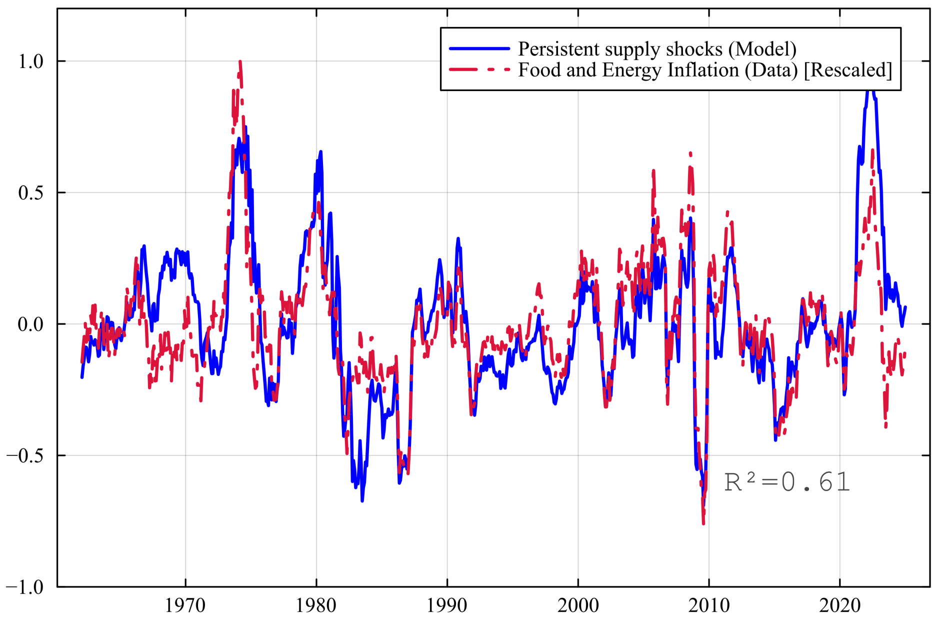

Figure 9: **Relative prices and perceptions about inflation**

Note: Persistent supply shocks as perceived by the agents vs inflation in food and energy prices (Untargeted). Measure of Food and Energy inflation is constructed as the difference between headline and core CPI inflation

7 Conclusions

The rational expectations revolution—spearheaded by the work of Lucas and Sargent—marked a profound shift in macroeconomic thought. New Keynesian macroeconomics incorporated this transformation by explicitly modeling how aggregate outcomes emerge from the optimizing behavior of individual agents. The model developed in this paper extends the forward-looking New Keynesian framework to an environment of imperfect knowledge, in which agents form and update beliefs about the economy using a structural model. In doing so, it describes postwar U.S. macroeconomic dynamics from the perspective of agents operating within a New Keynesian economy, learning about its structural drivers in real-time.

A central implication of the model is that, because expectations play a pivotal role in shaping macroeconomic outcomes, the function of monetary policy extends beyond mechanical stabilization. Policy actions not only influence current economic conditions but also actively shape agents' expectations—a point first emphasized by Kydland and Prescott (1977). The learning mechanism embedded in the model illustrates how the anchoring of expectations emerges endogenously from the systematic conduct of monetary policy. The evolution of postwar U.S. macroeconomic dynamics is thus closely linked to how Federal Reserve policymakers have signaled their underlying stabilization objectives. The model provides a structural interpretation of how monetary policy contributes to the anchoring of expectations, highlighting its dual role as both a stabilizing instrument and a signal relaying information and affecting expectations.

Perceived changes in the Federal Reserve's policy priorities — specifically, a heightened emphasis on unemployment stabilization has contributed to the anchoring of the long-run inflation expectations, cushioning the long-run anchor against perceived policy mistakes; while simultaneously amplifying the inflationary impact of persistent supply shocks. From the lens of the model, these perceptions were the principal reason that the Fed could "look-through" supply shocks without de-anchoring long-run expectations. Beliefs shaped by the disciplined conduct of monetary policy over the forty years following the Volcker disinflation have contributed greatly to the "soft-landing" that we saw recently. While recent work (e.g., Coibion and Gorodnichenko (2025)) has warned of inflationary risks resulting from de-anchoring of expectations from inflationary pressures in the short-run, the model presented here paints a less grim picture while recognizing the risks that an indecisive policy response to supply shocks could pose in the future.

This work also highlights the explanatory power of the textbook New-Keynesian model when augmented with imperfect information and learning. The model reconciles the empirically observed persistence in macroeconomic aggregates, delivering an excellent fit to macroeconomic data without resorting to backward-looking mechanisms such as indexation to past prices, habit formation in consumption or interest rate smoothing. Finally, the model highlights the *state-dependent* nature of agents' learning: the rate at which information arrives is neither uniform over time nor identical across structural parameters. One key parameter for which this distinction is particularly relevant is the slope of the expectations-augmented Phillips curve, which remains poorly identified under learning. This finding suggests that the full-information assumption commonly imposed in macroeconomic models may be far less innocuous than often presumed.

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8 Appendix

A Long-run inflation expectations

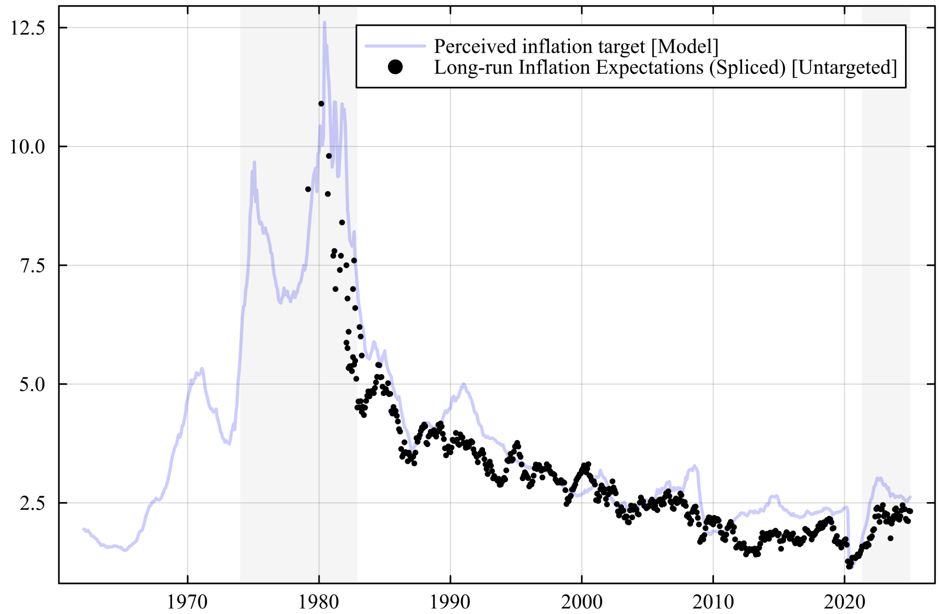
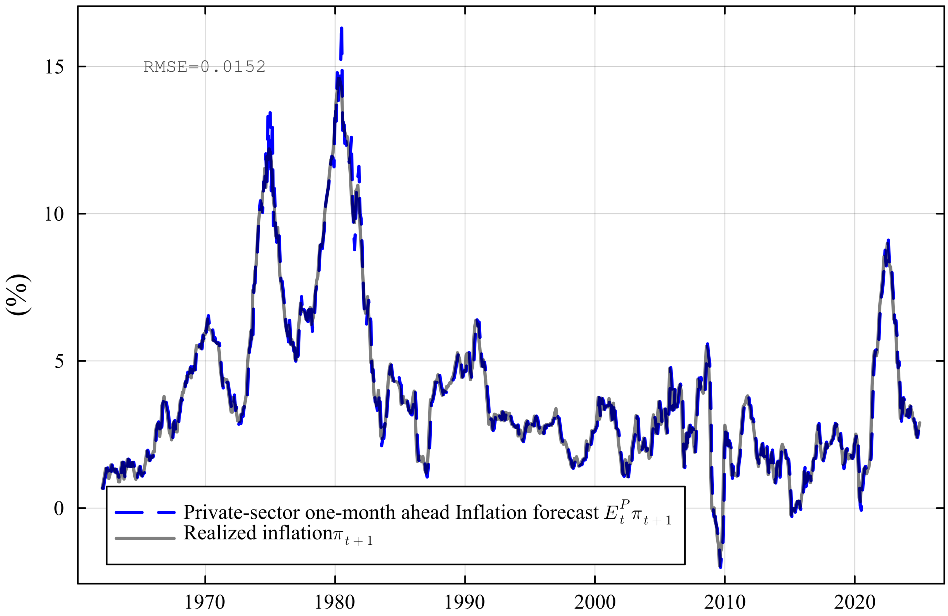


Figure 10: **Comparing with untargeted measures of long-run inflation expectations**

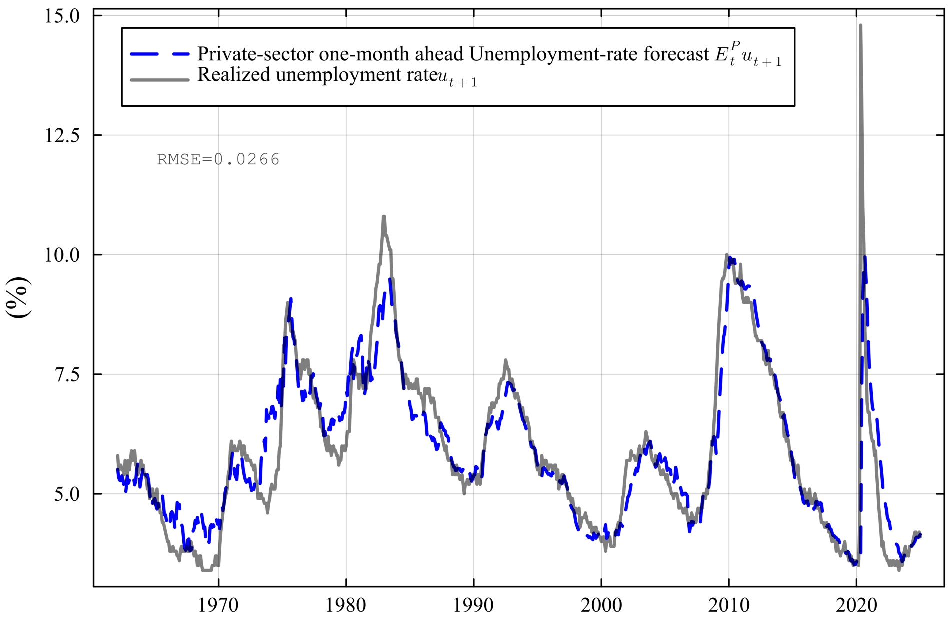
Note: Long-run Inflation Expectations series is constructed by splicing together 5-year ahead inflation expectations from Michigan Survey before 1982 and 10-year ahead inflation expectations from the Cleveland Fed afterwards (due to a shorter sample). The series is not used for estimation and is hence untargeted.

B Forecast performance of agents' model

If the learning algorithm arising from the agents' assumed model of economic dynamics implies forecasts that are persistently off-target, it wouldn't make sense to assume that the agents would continue using it. Rational agents would abandon the model. Hence, it is useful to check how well the agents' ex-ante forecasts agree with the realizations of the inflation, unemployment rate and interest rates or in other words if the agents' assumed model remains plausible given what they observe. Figure 12 plots the agents' ex-ante expectation of the policy rate (prior to announcement) and the realized effective Fed funds rate. Similarly, in Figure 11 I plot the agents' one-period ahead forecasts of inflation and unemployment rate against their corresponding realized values.



(a) Agents' one-month ahead forecast of inflation vs realized value



(b) Agents' one-month ahead forecast of unemployment rate vs realized value

Figure 11: **Forecast performance of agents' model**

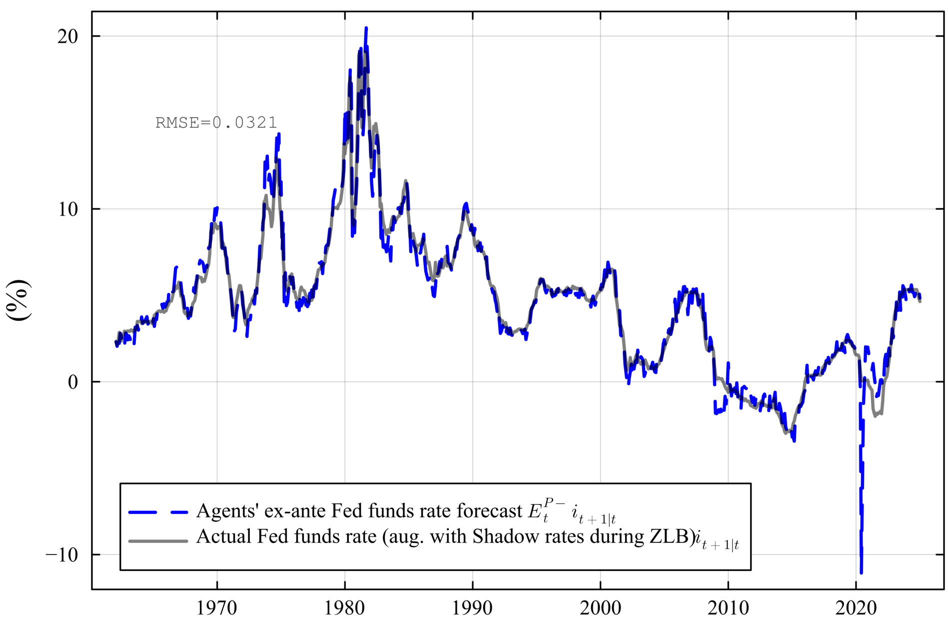


Figure 12: **How well do private agents track policy behavior?**

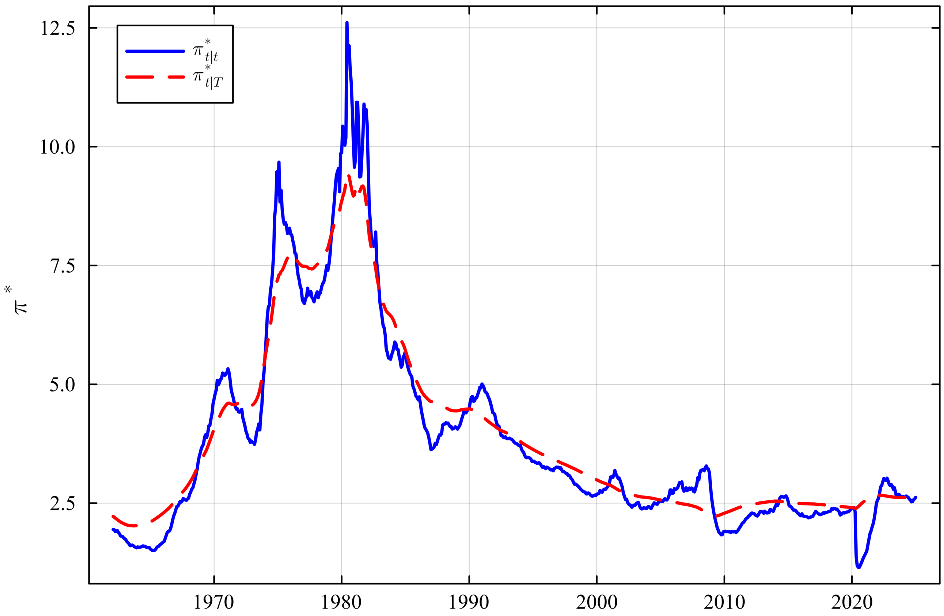
Note: The figure compares the private agents' expected nominal interest rates based on their ex-ante beliefs with the actual Fed funds rate (augmented with the shadow rate).

The learning model generates forecasts errors of small magnitude (in the RMSE sense). Thus, their model of the economy "works" - they wouldn't find a compelling reason to abandon learning. What is also interesting is the fact that the time-series of their expectations displays a similar degree of persistence as the corresponding macroeconomic variables themselves. The fact that this happens despite their model not having mechanical sources of persistence is noteworthy. Hence, forces such as price-indexation and habit-formation in consumption do not seem to be necessary to generate persistence in the macroeconomic aggregates once the role of learning in agents' expectations-formation process is modeled, as also demonstrated in Milani (2007) and Erceg and Levin (2003).

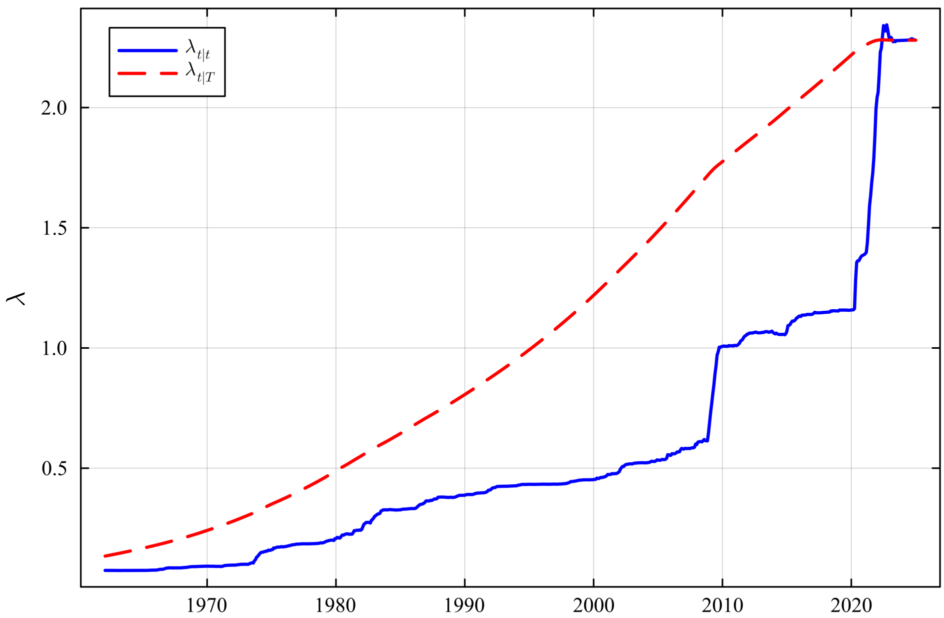
C What were the Fed's "true" policy preferences?

While the parameters representing the "true" policy preferences of the Fed over the post-war period remain latent (it evolves as an exogenous structural variable as far as the model is concerned), it is possible to arrive at a best-guess using the model by obtaining the smoothed (backward-looking) estimates of the time-t policy preferences (Figure 13). These estimates represent the evolution of Fed's policy preferences in the post-war period from the perspective of a private agent in the model looking back at the end of the sample period (Dec 2024). The estimates suggest that the Fed's true inflation target was upwards of 8 percent during the peak of the 80s-era inflation. Notably, the estimates of the time-varying inflation target are also in line with Ireland (2007) who uses a specification that is very different from the one used here.

Taken at face value, the smoothed estimates of λ suggest that Fed was hardly concerned with keeping the unemployment-gap closed during the 70s-80s. Over time however, the Fed has steadily emphasized closing the gap as part of its monetary policy strategy: which brings us to present-day. The estimated weight on unemployment-stabilization is almost twice as large as that on inflation-stabilization. The backward-looking estimates of λ_t display periods of departure from the real-time ones. This is because meaningful information regarding λ only arrives during periods where agents perceive large cost-push shocks driving policy tradeoffs (since λ is only relevant to policy when such a trade-off exists). Thus from the private agents' perspective, though λ has been evolving continuously, information regarding λ only arrives in clumps during episodes involving large persistent cost-push shocks driving policy trade-offs. Not much learning regarding λ takes place during "normal" times.



(a) π_t^*: Filtered *(solid)* vs Smoothed *(dashed)* estimates



(b) λ_t: Filtered *(solid)* vs Smoothed *(dashed)* estimates

Figure 13: **The Fed's "true" policy preferences**

Note: The figure plots the smoothed estimates of π_t^* and λ_t along with the filtered estimates. The smoothed estimates represent the agents' best-estimates of the parameters representing the Fed's policy preferences conditional on the entire sample period.

D Unemployment gap

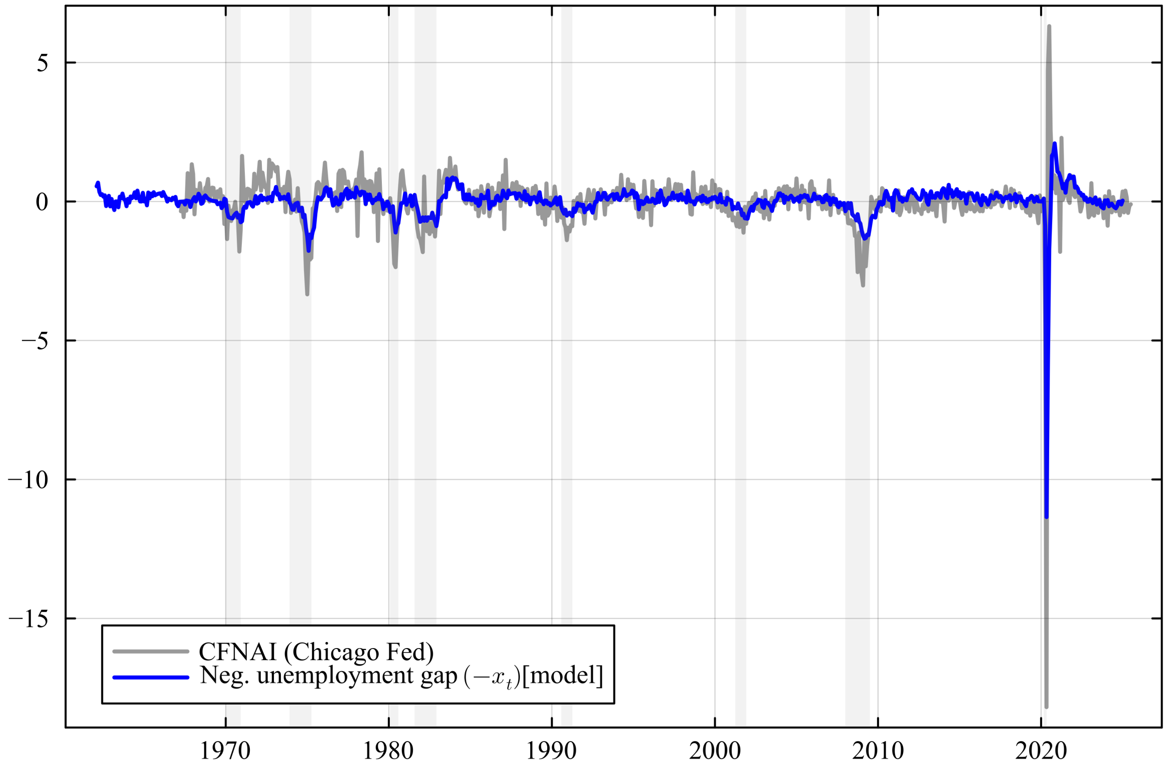


Figure 14: **Estimated unemployment-gap**

Note: The figure plots the agents' real-time estimates of the (negative of) unemployment gap with the CFNAI (Chicago Fed National Activity Index), a composite measure of real activity based on 81 series. The shaded regions indicate NBER recessions. CFNAI is obtained from the Chicago Fed website.

E Perceived natural rate of interest $r^n_{t|t}$

Figure 15 plots the evolution of the natural rate of interest as inferred by agents in real-time. This is a useful measure and serves as a barometer to gauge the stance of policy.

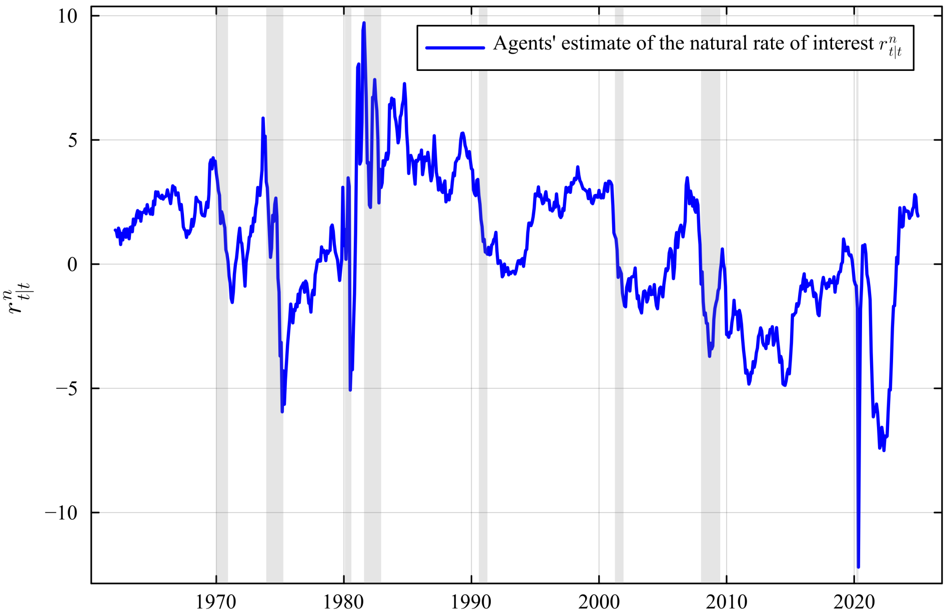


Figure 15: **Estimates of the natural rate of interest**

Note: Shaded regions indicate NBER recessions

F Testing the assumptions

F.1 Has the "true" slope of the Phillips curve changed over time?

In the baseline model, we proceeded with the assumption of a time-invariant Phillips curve in order to keep the model parsimonious and avoid over-reliance on time-variation Phillips curve to explain the observations. However, one can statistically test if there has been a change in the true relationship between unemployment-gap and inflation during the pandemic (motivated by literature arguing that structural shifts in the Phillips curve during the pandemic period were an important factor driving the inflation surge).

In order to do this, we can construct an expectation-adjusted measure of inflation π_t^{adj} as:

$$\pi_t^{adj} = \pi_t - E_{t-1}^P \pi_{t+1}$$

This expectations-adjusted measure of inflation is regressed against the unemployment-gap variable x_t. The OLS result would not recover the true underlying κ since we would expect x_t to be correlated with the supply shock ξ_t. It will only be able to recover the reduced-form relationship between inflation and unemployment gap, not any structural linkage. The results of the baseline regression show that once expectations are taken into account, the relationship between inflation and the unemployment-gap is statistically significant - implying a 1% increase in the unemployment-gap associated with a roughly 10 bp decrease in inflation. It is worth noting that the estimate is quite close to the agents' beliefs about κ at the end of the sample shown in Figure 5 (≈ -0.11). However, the second column shows that the dummy representing the difference in slope during the post-2020 period is not found to be statistically significant at the 5% confidence level.

Table 2: Expectations-augmented Phillips curve: Examining change in slope

	Model 1 Baseline	Model 2 Change in slope post-2020
$\hat{x}_t$	**-0.106****	**-0.193****
	(0.037)	(0.063)
$\hat{x}_t \times \mathbf{1}_{\{t>2020\}}$	—	0.119
		(0.067)
Observations	756	756
R^2 (uncentered)	0.023	0.028
F-stat	8.322	10.42
p-value	0.004	3.44e-05

Notes: Dependent variable is π_t^{adj}. Model 2 augments Model 1 with the interaction $x_t \times \mathbf{1}_{\{t>2020\}}$, where $\mathbf{1}_{\{t>2020\}}$ equals one for dates from 2020 onward. HAC (Newey–West) robust standard errors (Bartlett kernel, maxlags = 6). R^2 is computed without centering because the model has no constant. Significance: * indicates that the coefficient is significant at the 5% level.

Another way to shed light on whether time-variation in the Phillips curve slope is an important feature of economic dynamics necessary to explain the data is to directly test for time-variation in the κ_t against the null of a constant-κ_t in the relationship:

$$\pi_t^{adj} = -\kappa_t x_t + \xi_t$$

If the data supports time-variation in κ_t, then relaxing the restriction of a constant κ should result in a significantly better fit, as measured by log-likelihood. A likelihood-ratio (LR) test is conducted, testing the alternate hypothesis of time-variation in κ against the null of a constant κ. The LR test is not statistically significant with $p \approx 1.00$. This suggests that the model finds no evidence in favor of time-variation slope of the Phillips curve once expectations are accounted for. The results of the test are reported in Table 3. Re-estimating the model with a time-varying slope κ (allowing for innovations with a reasonably small variance 10^{-3} over time) produces nearly identical paths of beliefs as the baseline. Overall, the results suggest that changes in the slope of the structural Phillips curve are not a necessary feature to explain post-war U.S. economic dynamics.

Table 3: Results of the Likelihood Ratio Test

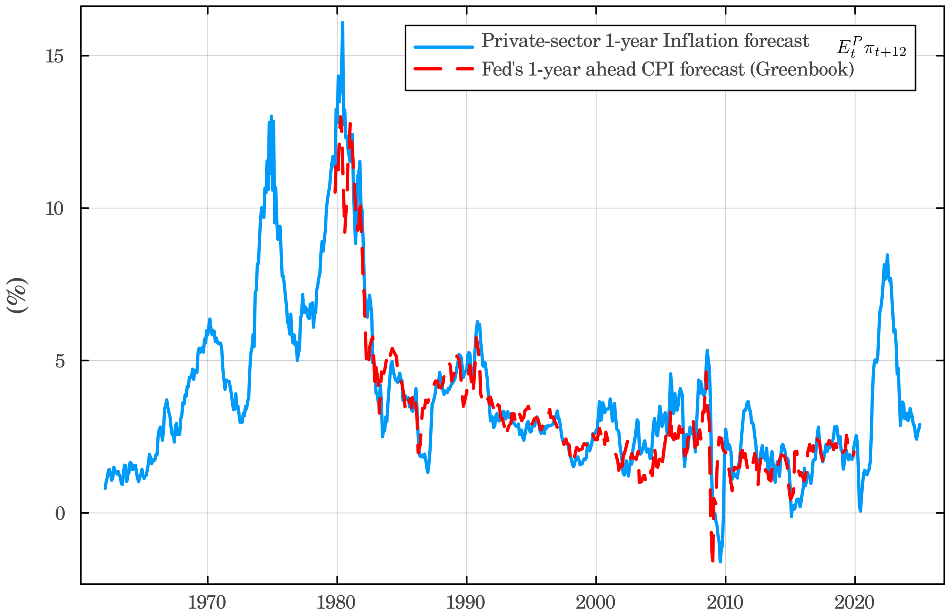
Model	**Log-Likelihood**	**Parameters**	χ^2	**df**	**p-value**
Restricted (Constant κ)	-402.460	3	3.1×10^{-7}	1	1.000
Full (Time-Varying κ)	-402.460	4			

Note: The restricted model assumes a constant κ coefficient, while the full model allows it to vary over time. The constant parameter case is nested within the full time-varying parameter model. The Likelihood Ratio Test (LRT) statistic (χ^2) is calculated as $2 \times (\log L_{\text{Full}} - \log L_{\text{Restricted}})$, with degrees of freedom (df) equal to the difference in the number of parameters between the two models.

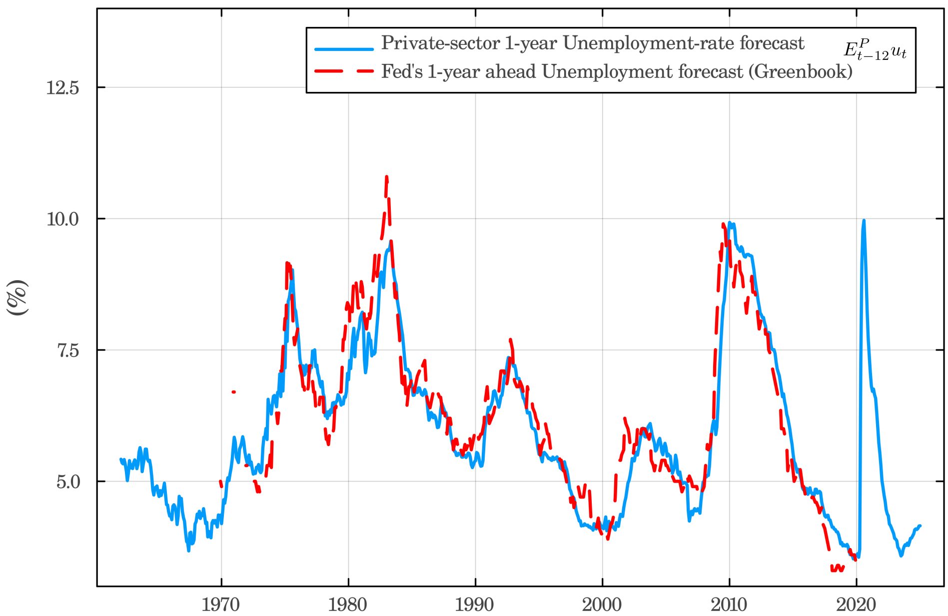
Overall, these results favor the view that time-invariant Phillips curve view adopted by the private agents in the model. Since the modeling framework in this paper explicitly accounts for endogenous formation of expectations, κ should not be interpreted as a purely a statistical relationship between inflation and unemployment, differently from the classical Keynesian specification of the Phillips curve described by Phillips (1958).

F.2 Is the degree of information asymmetry small or large?

This paper assumes little information asymmetry between the Fed and the private-sector: (i) their beliefs about the structural parameters and shocks in the economy are shaped by the same data and the same economic model (ii) the filtering problem assumes that private-agents are able to track the true policy preferences efficiently, meaning that their tracked estimates never stray away from the "true" underlying parameters describing the Fed policymakers' stabilization preferences. One way to test whether these assumptions hold well during the sample period is to compare the agents' forecasts as implied by the model with those from the Greenbook: the Fed's internal forecasts prepared by the staff before each FOMC meeting. If the Fed policymakers do hold significantly different beliefs compared to the private agents, then it would be reflected as a discrepancy in their forecasts.



(a) **Inflation forecasts:** Comparing the Fed's 1-year ahead Headline CPI inflation forecast from Greenbook with 1-year ahead private-agents' forecasts from the baseline model



(b) **Unemployment rate forecasts:** Comparing the Fed's 1-year ahead unemployment rate forecast from Greenbook with 1-year ahead private agents' forecasts from the baseline model

Figure 16: **Macroeconomic outlook: Fed (Greenbook) vs Private Agents (Model)**

To the extent that asymmetric information is large enough to drive a wedge between private agents' and the Fed's forecasts, it does not seem to be important during the sample period.

Private-sector forecasts as implied by the model are very close to the corresponding internal forecasts of the Fed (as observed in the Greenbook).