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Anchored Inflation Expectations and the Slope of the Phillips Curve*

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Abstract

It is conventional wisdom that the reduced form Phillips curve has become flatter in recent decades. Accordingly, we show that the statistical relationship between *changes* in U.S. inflation and economic activity has become flatter. But in contrast, the statistical relationship between the *level* of inflation and economic activity has become *steeper.* By allowing for changes in the degree of anchoring of agents' inflation forecasts, we recover a stable structural slope coefficient in an estimated version of the New Keynesian Phillips curve from 1960 to 2019. Using a New Keynesian model with imperfect information, we propose a novel general equilibrium channel through which improved anchoring of expected inflation can help explain the observed changes in the reduced form Phillips curve relationships.

Keywords: *Inflation expectations, Phillips curve, Inflation puzzles, Imperfect information.*
JEL Classification: E31, E37

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The slope of the Phillips curve—a measure of the responsiveness of inflation to a decline in labor market slack—has declined very significantly since the 1960's. In other words, the Phillips curve appears to have become quite flat. Janet Yellen (2019)

The relationship between slack in the economy... and inflation was a strong one 50 years ago... and that has gone away. Jerome Powell (2019)

1 Introduction

There is widespread consensus among economists and policymakers that the reduced form Phillips curve has become flatter in recent decades. This idea is clearly evident in the above quotes. But the meaning of the phrase "a flatter Phillips curve" is ambiguous without a clear definition of the reduced form relationship being described. Some authors refer to the so-called "accelerationist" Phillips curve which links *changes* in inflation to economic activity (Bernanke 2007, Blanchard 2016, Stock and Watson 2020, Hazell, et al. 2022). Others refer to the statistical relationship between the *level* of inflation and economic activity (Bullard 2018, McLeay and Tenreyro 2020). While this distinction may not seem that important, we show below that it is.

The left panel of Figure 1 plots the CBO output gap against the 4-quarter *change* in the 4-quarter core CPI inflation rate, both before and after 1999.[1] This specification is commonly referred to as an accelerationist Phillips curve. The figure shows that changes in inflation have become less sensitive to the output gap over the past 20 years, making the accelerationist Phillips curve flatter. This stylized fact has been widely documented in the empirical literature.

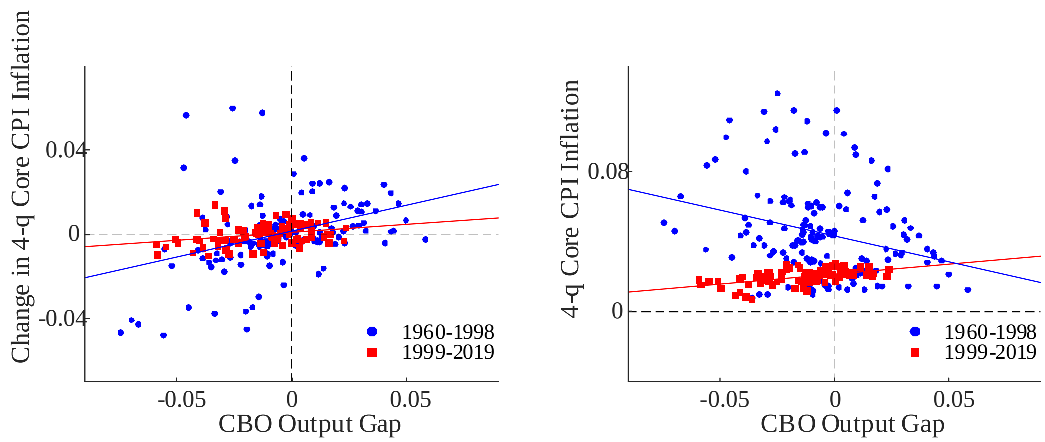
In contrast, the right panel of Figure 1 plots the CBO output gap against the *level* of 4-quarter core CPI inflation. The reduced-form regression is reminiscent of the original 1958 version of the Phillips curve. We refer to this specification as the "original" Phillips curve.[2] For the period from 1960 to 1998, the slope is negative, but not statistically significant. However, since the late 1990s, a positive and highly statistically significant relationship between the

[1] As we show, the date 1999.q1 is approximately when the anchoring process for expected inflation appears to have been completed. The sample period from 1999.q1 onward can be viewed as an example of consistent U.S. monetary policy with well-anchored inflation expectations.

[2] Phillips (1958) documented an inverse relationship between wage inflation and unemployment in the United Kingdom.

level of inflation and the output gap has emerged.[3]

Figure 1: *Has the Phillips curve become "flatter"?*



Note: The left panel plots fitted lines of the form: $\pi_{4,t} - \pi_{4,t-4} = c_0 + c_1 y_t$, where $\pi_{4,t}$ is the 4-quarter core CPI inflation rate and y_t is the CBO output gap. The right panel plots fitted lines of the form: $\pi_{4,t} = c_0 + c_1 y_t$.

Facts. Table 1 summarizes four stylized facts about U.S. inflation:

1. The statistical relationship between *changes* in inflation and economic activity, known as the "accelerationist" Phillips curve, has become flatter.

2. The statistical relationship between the *level* of inflation and economic activity, which we refer to as the "original" Phillips curve, has become steeper.

3. Inflation volatility has declined.

4. Inflation persistence has declined.

The right-most panel of Table 1 shows that these patterns were present in the data prior to the onset of the Great Recession. In Appendix B, we show that the stylized facts in Table 1 are robust to using alternative subsamples of U.S. data (pre- and post-1984.q1), an alternative measure of inflation (core PCE inflation), or alternative measures of economic activity (detrended real GDP, the unemployment gap, and the unemployment rate).[4]

[3]The slope coefficient is statistically significant at the 1 percent level. The R^2 value of the regression is 0.28.

[4]Campbell, Pflueger, and Viceira (2020) identify a statistically significant break in the correlation between inflation and the output gap (going from negative to positive) around the date 2001.q2.

Table 1: Moments of U.S. inflation

	1960.q1 to 1998.q4	1999.q1 to 2019.q2	1999.q1 to 2007.q3
$Cov\left(\Delta\pi_t, y_t\right)/Var\left(y_t\right)$	0.03	0.00	0.01
$Corr\left(\Delta\pi_t, y_t\right)$	0.14	0.03	0.07
$Cov\left(\pi_t, y_t\right)/Var\left(y_t\right)$	-0.03	0.04	0.04
$Corr\left(\pi_t, y_t\right)$	-0.10	0.36	0.28
$Std.\ Dev.\left(4\pi_t\right)$	2.91	0.80	0.77
$Corr\left(\pi_t, \pi_{t-1}\right)$	0.75	0.20	0.20

Note: π_t is quarterly core CPI inflation, y_t is the CBO output gap, and $\Delta\pi_t = \pi_t - \pi_{t-1}$. Standard deviations are in percent. Data sources are described in Appendix A.

This paper. The observation of a steeper original Phillips curve is important because it contradicts some proposed explanations for a flatter Phillips curve. Suppose that the true data generating process is governed by a New Keynesian Phillips curve (NKPC):

$$\pi_t = \beta\widetilde{E}_t\pi_{t+1} + \kappa y_t + u_t, \qquad \kappa > 0, \;\; u_t \sim N\left(0, \sigma_u^2\right), \tag{1}$$

where π_t is the quarterly inflation rate (log difference of the price level), $\widetilde{E}_t\pi_{t+1}$ is the one-period ahead inflation forecast, y_t is the output gap (the log deviation of real output from potential output), u_t is an *iid* cost-push shock, β is the subjective discount factor, and κ is the structural slope parameter.[5]

The NKPC (1) implies that the slope of the original Phillips curve shown in the right panel of Figure 1 is given by:

$$\frac{Cov\left(\pi_t, y_t\right)}{Var\left(y_t\right)} = \frac{Cov(\widetilde{E}_t\pi_{t+1}, y_t)}{Var\left(y_t\right)} \;+\; \kappa \;+\; \frac{Cov\left(u_t, y_t\right)}{Var\left(y_t\right)}. \tag{2}$$

Many papers attribute the flatter Phillips curve to a decline in the structural slope parameter κ (Ball and Mazumder 2011, IMF 2013, Blanchard, Cerutti, and Summers 2015, Del Negro, et al. 2020). Other authors argue that stabilizing monetary policy, in the presence of cost-push shocks u_t, has weakened the statistical relationship between inflation and economic activity. (Bullard 2018, McLeay and Tenreyro 2020). This effect would serve to reduce the value of $Cov\left(u_t, y_t\right)/Var\left(y_t\right)$. But as equation (2) shows, both of these proposed explanations would contribute to a weaker statistical relationship between π_t and y_t.[6] In contrast, Table 1 shows

[5] Equation (1) can be derived from the sticky price model of Calvo (1983) or the menu cost model of Rotemberg (1982). For the derivation, see Clarida, Galí, and Gertler (2000) or Woodford (2003b). The derivation requires that the Law of Iterated Expectations is satisfied (Adam and Padula 2011). This is the case when agents have Full Information Rational Expectations (FIRE), but also when agents are rational but imperfectly informed. Coibion and Gorodnichenko (2018) show that SPF inflation forecasts do in fact appear to satisfy the Law of Iterated Expectations.

[6] Bullard (2018, p. 15) and McLeay and Tenreyro (2020, Table 1) both show that the optimal policy response to inflation, in the presence of cost push shocks, will serve to reduce the slope coefficient $Cov\left(\pi_t, y_t\right)/Var\left(y_t\right)$.

that the statistical relationship between π_t and y_t has become stronger in recent decades. An increase in the importance of demand shocks relative to cost-push shocks could help explain a steeper original Phillips curve but, all else equal, would not explain a flatter accelerationist Phillips curve or account for the large reductions in inflation volatility and persistence shown in Table 1.

Using both empirical evidence and a theoretical model, we show that the improved anchoring of agents' inflation expectations provides a coherent explanation for the shifting inflation behavior summarized in Table 1.

On the empirical side, we recover a stable structural NKPC relationship using aggregate U.S. data covering the period from 1960 to 2019. The model resolves both the "missing disinflation puzzle" (Coibion and Gorodnichenko 2015a) during the Great Recession and the "missing inflation puzzle" (Constâncio 2015) during the subsequent recovery. Specifically, we assume that expected inflation evolves according to the following law of motion:

$$\widetilde{E}_t \pi_{t+1} = \widetilde{E}_t \pi_t^* = \ \widetilde{E}_{t-1} \pi_t + \lambda(\pi_t - \widetilde{E}_{t-1} \pi_t). \tag{3}$$

As we show in the theoretical section of the paper, equation (3) can be derived from a standard New Keynesian model with imperfect information, where π_t^* is the central bank's inflation target and $\widetilde{E}_t \pi_t^*$ is the agent's current Kalman filter estimate of π_t^*. The gain parameter $\lambda \in (0, 1]$ governs the sensitivity of expected inflation to short-run inflation surprises. This parameter can be viewed as measuring the degree of anchoring in agents' inflation forecasts, with lower values of λ implying that expectations are more firmly anchored. This interpretation is consistent with the definition provided by Bernanke (2007): *"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."* Equation (3) is consistent with survey data on actual expectations, including inflation expectations, as measured by the Survey of Professional Forecasters (SPF).[7] Notably, Coibion and Gorodnichenko (2015b) show that ex-post mean inflation forecast errors from the SPF can be predicted using ex-ante mean forecast revisions, consistent with a forecast rule of the form (3).

When expected inflation in the NKPC is given by equation (3), the estimated value of λ declines substantially over the Great Moderation period, indicating that inflation expectations

[7] A large body of empirical evidence suggests that inflation forecasts of households and professionals are well described by forecast rules of the type (3). See, for example, Mankiw, Reis, and Wolfers (2003), Lansing (2009), Kozicki and Tinsley (2012), Coibion and Gorodnichenko (2012, 2015b, 2018) and Bordalo, et al. (2020).

have become more firmly anchored since the mid-1980s.[8] The estimated coefficient on the output gap is highly statistically significant and stable over the period 1960 to 2019. If instead the NKPC is estimated using survey data on long-run expected inflation in place of equation (3), then we obtain very similar slope coefficients, again confirming that the structural Phillips curve relationship in the data remains alive and well.

We use the estimated Phillips curve to generate model-predicted paths for inflation and expected inflation conditional on the actual path of the CBO output gap over the period from 2007.q4 to 2019.q2. When expected inflation is given by equation (3), the NKPC can largely account for the behavior of inflation and long-run expected inflation from surveys from 2007.q4 onward. The estimated value of λ implies that agents' inflation forecasts were well-anchored (but not perfectly anchored) prior to the start of the Great Recession. The well-anchored forecasts deliver a muted response of inflation to the highly-negative output gap observed during the Great Recession. Nevertheless, the persistent negative gap episode brings about a gradual downward drift in the model-predicted path for long-run expected inflation. As a result, the model-predicted path for actual inflation persistently undershoots the Fed's inflation target. According to this version of the NKPC, there is no missing disinflation puzzle in the wake of the Great Recession and no missing inflation puzzle during the subsequent recovery.[9]

On the theoretical side, we use a simple New Keynesian model with imperfect information to demonstrate how imperfectly anchored inflation expectations influence reduced form Phillips curve relationships. Following Erceg and Levin (2003), we assume that private sector agents cannot directly observe the central bank's inflation target. Instead, they solve a signal extraction problem to infer the inflation target using observable data. Agents seek to disentangle transitory demand and cost-push shocks from highly persistent shocks to the inflation target. The model delivers the univariate forecast rule (3) as the optimal forecast. The value of the gain parameter λ depends on the signal-to-noise ratio which in turn depends on the relative variances of the persistent versus transitory shocks to inflation. A reduction in the variance of inflation target shocks serves to reduce the optimal value of λ, making expected inflation more firmly anchored. This result is consistent with a popular view among econo-

[8] This result is consistent with the findings of Stock and Watson (2007, Figure 2), Lansing (2009, Figure 5) and Carvalho, et al. (2023, Figure 2) who obtain declining estimates of model-defined gain parameters in U.S. data, implying improved anchoring of agents' inflation expectations.

[9] Del Negro et al. (2015) also emphasize the importance of well-anchored inflation expectations in explaining the missing disinflation puzzle. Alternative accounts of the missing inflation puzzle have invoked the role played by the zero lower bound (ZLB) on nominal interest rates. See, for example, Hills, Nakata, and Schmidt (2019), Mertens and Williams (2019), and Lansing (2021).

mists that a change in monetary policy accounts for the improved anchoring of U.S. inflation expectations.

Next, we show that our model of expectations anchoring can account for the shifts in the reduced-form Phillips curve relationships shown in Figure 1. Previously, Bernanke (2007) has pointed out that improved anchoring of expected inflation reduces the sensitivity of expected inflation (and hence inflation itself) to variations in economic activity.[10] This mechanism would serve to reduce $Cov(\widetilde{E}_t\pi_{t+1}, y_t)/Var\,(y_t)$ in equation (2) and thus reduce $Cov\,(\pi_t, y_t)\,/Var\,(y_t)$. However, as shown in Table 1, this prediction is counterfactual.[11] To our knowledge, our paper is the first to examine the effects of improved anchoring for reduced form Phillips curve relationships in a general equilibrium model.[12] We propose a novel general equilibrium channel through which improved anchoring of expected inflation serves to flatten the accelerationist Phillips curve but *steepen* the original Phillips curve.[13]

Our proposed mechanism works through inflation persistence. To briefly illustrate the intuition, consider the effects of a positive white noise demand shock which increases the output gap and leads to higher inflation via the NKPC. If there is no intrinsic persistence in the model, the white noise shock has no effect on expected inflation under full information rational expectations. In this case, expectations are perfectly anchored. However, if expectations are imperfectly anchored due to agents' inability to observe the inflation target, then the white noise shock will generate a persistent increase in expected inflation and hence a persistent increase in actual inflation via the NKPC. An inflation-targeting central bank will respond to the persistent rise in inflation by lowering the output gap, generating *negative* co-movement between inflation and the output gap in the periods after the shock.[14] This mechanism induces a downward bias in the slope of the original Phillips curve but a corresponding upward bias in the accelerationist Phillips curve slope, relative to the true structural slope parameter in the NKPC. Both of these biases will shrink if the signal extraction problem eases, allowing inflation

[10] Bernanke (2007) stated: *"If inflation expectations respond less than previously to variations in economic activity, then inflation itself will become relatively more insensitive to the level of activity."*

[11] In Appendix C, we use various measures of expected inflation from surveys to show that the value of $Cov(\widetilde{E}_t\pi_{t+1}, y_t)/Var\,(y_t)$ has *increased* over time in U.S. data (going from a negative value to a near-zero or positive value).

[12] Note that Bernanke's (2007, 2010) anchored expectations hypothesis was laid out in speeches and never formalized in a macroeconomic model.

[13] Improved anchoring of expected inflation also reduces the sensitivity of expected inflation (and hence inflation itself) to cost-push shocks. This mechanism would also influence the reduced form Phillips curve. However, we do not emphasize it here, because it cannot explain the flattening of the accelerationist Phillips curve.

[14] This point is related to Ascari, et al. (2022) who find that shocks to inflation expectations have similar effects as cost-push shocks, inducing negative co-movement between inflation and output in U.S. data.

expectations to become more firmly anchored. In this way, the transition to a policy regime with a transparent and constant inflation target serves to lower inflation persistence, flatten the accelerationist Phillips curve but steepen the original Phillips curve. The same mechanism leads to a decline in inflation volatility. All of these model predictions are consistent with the empirical observations summarized in Table 1.

Related literature. Our paper contributes to a large literature on the implications of anchored inflation expectations for the Phillips curve relationship (e.g., Williams 2006, Bernanke 2007, IMF 2013, Kiley 2015, Blanchard 2016, Bundick and Smith 2020, Afrouzi and Yang 2021, Hasenzagl, et al. 2022, Barnichon and Mesters 2021, Hazell, et al. 2022).

Roberts (2006), Mishkin (2007) and Bernanke (2007) were among the first to argue that improved anchoring of expected inflation can help explain the flattening of the accelerationist Phillips curve and reductions in inflation volatility and persistence. Stock and Watson (2010), Stock (2011) and Ball and Mazumder (2019) show that improved anchoring of expected inflation can help explain the decline in the estimated slope coefficient in accelerationist Phillips curve regressions. Using cross-country data, Bems et. al. (2021) find that improved anchoring of expected inflation is associated with lower values of inflation persistence. Blanchard, Cerutti, and Summers (2015) and Blanchard (2016) point out that improved anchoring of expected inflation implies that the structural Phillips curve shifts from an accelerationist-type Phillips curve to one that resembles the original Phillips curve. Along these lines, Jørgensen and Lansing (2021) show that changes in U.S. inflation are no longer driven by the output gap itself, but rather by changes in the output gap. Our results are consistent with all of the above-mentioned findings. A key contribution of our paper is to identify a novel general equilibrium channel through which the endogenous anchoring of expected inflation can explain both the observed flattening of the accelerationist Phillips curve and the observed steepening of the original Phillips curve.

Rational agents in our model solve a signal-extraction problem to infer the central bank's unobservable inflation target. Other examples of this setup in the literature include Andolfatto and Gomme (2003), Erceg and Levin (2003), Schorfheide (2005), Andolfatto, et al. (2008), Meleck, et al. (2009), Keen (2010), Del Negro and Eusepi (2011). Conditional on their information set, agents use optimal filtering methods to infer the unobservable state, as in Woodford (2003a). This feature distinguishes our work from models of expectations anchoring with boundedly-rational agents, such as Lansing (2009), Milani (2014), Carvalho, et al. (2023), and Gati (2022).

Several recent papers have shown that the NKPC relationship appears to be stable when estimated using survey-based measures of inflation expectations (Coibion and Gorodnichenko 2015a, Coibion, Gorodnichenko, and Kamdar 2018, Coibion, Gorodnichenko, and Ulate 2019, Crump, et al. 2019). Our results confirm these findings. The main empirical contribution of our paper, however, is to explicitly model the anchoring process, which in turn allows us to document a stable NKPC slope coefficient in aggregate U.S. data going back to the 1960s. Our findings for the U.S. economy are in line with those of Hazell, et al. (2022) who estimate the NKPC using state-level data. They find that the slope of the NKPC has been roughly stable over time and that changes in inflation dynamics are mostly due to the improved anchoring of expected inflation.

Our empirical results using data through 2019.q2 indicate that the New Keynesian Phillips curve has not become structurally flatter. But if the Phillips curve is perceived to be flat when in fact it is not, then policymakers could allow the economy to run too hot, leading to a persistent surge in inflation that, in turn, could degrade the anchoring of agents' inflation expectations. The sharp rise in U.S. inflation starting in early 2021 may turn out to be such an example (Summers 2021).

Outline. The remainder of the paper proceeds as follows. In Section 2, we estimate four versions of the NKPC that vary according to the way that inflation expectations are formed. Section 3 presents model-predicted inflation paths for the period from 2007.q4 to 2019.q2. Section 4 uses a simple New Keynesian model with imperfect information to examine the theoretical links between the monetary policy regime, the degree of anchoring in agents' inflation forecasts and slopes of reduced form Phillips curves. Section 4 can be read independently from the empirical results in Sections 2 and 3. Section 5 concludes. The Appendix describes our data sources and provides numerous robustness checks of our empirical results.

2 Estimation of the NKPC

In this section, we examine the empirical question of whether the structural slope parameter of the NKPC has declined over time. We estimate four versions of equation (1) that vary according to the way that inflation expectations are formed. For simplicity, we assume $\beta \simeq 1$ in all specifications, but none of our results are sensitive to this assumption.

2.1 Four specifications of expected inflation

The four specifications of expected inflation that we employ are given by

$$\begin{aligned}
\widetilde{E}_t\pi_{t+1} &= \gamma_f \, E_t\pi_{t+1} + \left(1-\gamma_f\right)\pi_{t-1}, \qquad 0 \le \gamma_f \le 1, && (4)\\
\widetilde{E}_t\pi_{t+1} &= \left(\pi_{t-1} + \pi_{t-2} + \pi_{t-3} + \pi_{t-4}\right)/4, && (5)\\
\widetilde{E}_t\pi_{t+1} &= \widetilde{E}_t\pi_t^* = \widetilde{E}_{t-1}\pi_t + \lambda(\pi_t - \widetilde{E}_{t-1}\pi_t) && (6)\\
&= \lambda\left[\pi_t + (1-\lambda)\pi_{t-1} + (1-\lambda)^2\pi_{t-2} + ...\right], \\
\widetilde{E}_t\pi_{t+1} &= \widetilde{E}_t^s\pi_{t+h}. && (7)
\end{aligned}$$

Equation (4) is the model employed by Galí and Gertler (1999) in estimating a so-called "hybrid" NKPC, where expected inflation can be viewed as a weighted average of a full information rational expectations (FIRE) component $E_t\pi_{t+1}$ (where E_t is the mathematical expectations operator) and a backward-looking component π_{t-1}. The backward-looking component can be microfounded by assuming that a fraction of firms index their prices to past inflation each period (Christiano, Eichenbaum, and Evans 2005). Equation (5) is the purely backward-looking, accelerationist specification employed by Ball and Mazumder (2011). As we demonstrate in Section 4, equation (6) is the optimal inflation forecast rule in a New Keynesian model where agents solve a signal extraction problem to infer the central bank's unobservable inflation target π_t^*. The term $\widetilde{E}_t\pi_t^*$ is the agent's optimal Kalman filter estimate of π_t^*, where the expectations operator $\widetilde{E}_t$ represents the conditional expectation based on information available to private sector agents in period t. Iterating equation (6) backwards in time shows that that expected inflation is given by an exponentially-weighted moving average of current and past inflation rates. The optimal value of the gain parameter λ depends positively on the signal-to-noise ratio which is a measure of the relative variances of the persistent and transitory shocks to inflation. A higher signal-to-noise ratio implies a higher likelihood of a persistent change, either upwards or downwards, in the inflation target. We will refer to equation (6) as the "imperfect information" model of expected inflation. In equation (7), $\widetilde{E}_t^s\pi_{t+h}$ is a survey-based measure of expected inflation at horizon h.

2.2 Empirical methodology

Following Galí and Gertler (1999), we estimate the hybrid NKPC using the Generalized Method of Moments (GMM) with lagged variables as instruments. This estimation strategy attempts to resolve two endogeneity problems in the NKPC: (1) the output gap y_t may be correlated with the cost-push shock u_t, and (2) the term $E_t\pi_{t+1}$ in the hybrid FIRE forecast rule (4) is endogenous.[15] Substituting the hybrid FIRE forecast rule into the NKPC (1) yields

$$\pi_t = \gamma_f \pi_{t+1} + \left(1-\gamma_f\right) \pi_{t-1} + \kappa y_t + \widetilde{u}_t, \tag{8}$$

where $\widetilde{u}_t \equiv u_t + \gamma_f \left(E_t\pi_{t+1} - \pi_{t+1}\right)$ is *iid.* To help control for the impacts of cost-push shocks on inflation, we use core inflation as our baseline inflation measure and include current and lagged oil price inflation as regressors.[16]

We estimate the hybrid FIRE version of the NKPC using the orthogonality condition

$$E_t\left\{\vartheta_{fire}\mathbf{z}_{t-1}\right\} = 0, \tag{9}$$

where

$$\vartheta_{fire} = \pi_t - \gamma_f \pi_{t+1} - \left(1-\gamma_f\right)\pi_{t-1} - \kappa y_t - \delta\pi_t^{oil} - \varphi\pi_{t-1}^{oil}, \tag{10}$$

is the residual, $\mathbf{z}_{t-1}$ is a vector of instruments dated $t-1$ and earlier, π_t^{oil} is quarterly oil price inflation, and γ_f, κ, δ, and φ are the parameters to be estimated.[17]

Similarly, we estimate the accelerationist and imperfect information versions of the NKPC using the orthogonality conditions $E_t\left\{\vartheta_a\mathbf{z}_{t-1}\right\} = 0$ and $E_t\left\{\vartheta_{ii}\mathbf{z}_{t-1}\right\} = 0$, where, respectively,

$$\vartheta_a = \pi_t - \left(\pi_{t-1} + \pi_{t-2} + \pi_{t-3} + \pi_{t-4}\right)/4 - \kappa y_t - \delta\pi_t^{oil} - \varphi\pi_{t-1}^{oil}, \tag{11}$$

$$\vartheta_{ii} = \pi_t - \widetilde{E}_{t-1}\pi_t - \frac{1}{1-\lambda}(\kappa y_t + \delta\pi_t^{oil} + \varphi\pi_{t-1}^{oil}). \tag{12}$$

The value of $\widetilde{E}_{t-1}\pi_t$ in equation (12) is updated using the lagged version of the imperfect information forecast rule (6).[18]

When estimating the NKPC using survey expectations, the orthogonality condition becomes

$$\vartheta_S = \pi_t - c - \widetilde{E}_t^s\pi_{t+h} - \kappa y_t - \delta\pi_t^{oil} - \varphi\pi_{t-1}^{oil}, \tag{13}$$

[15] Mavroeidis, Plagborg-Møller, and Stock (2014) point out that the endogenous expectations term may lead to weak identification problems. We emphasize that our proposed specification of the NKPC in which expectations are given by equation (6) does *not* have an endogenous expectations term. Also, our specification yields estimates of the structural slope coefficient that are both stable and large compared to other estimates in the literature (see Hazell, et al. 2022 for an overview). The latter suggests that we manage to control for cost-push shocks reasonably well.

[16] Following Hooker (2002), we include lagged oil price inflation as a regressor because the pass-through from oil prices to core inflation may occur with a lag.

[17] We use iterated GMM with a weight matrix computed using the Newey and West (1987) heteroskedasticity- and autocorrelation-consistent estimator with automatic lag truncation.

[18] For the first period of the estimation sample ($t = t_0$), we use the following initial condition: $\widetilde{E}_{t_0-1}\pi_{t_0} = 0.125\sum_{k=1}^{8}\pi_{t_0-k}$.

where $\widetilde{E}_t^s \pi_{t+h}$ is a survey-based measure of expected *headline* inflation at horizon h and c is a constant. The constant is included to account for historical differences between the average levels of headline and core inflation.

We use quarterly data for core CPI inflation, the CBO output gap, and oil price inflation for the sample period 1960.q1 to 2019.q2. Throughout the paper, we split the data into three subsamples. We use a smaller set of instruments than is used by Galí, Gertler, and López-Salido (2005). This is done to minimize the potential for small sample bias that may arise when there are too many over-identifying restrictions, as discussed by Staiger and Stock (1997). Our baseline set of instruments includes two lags each of core CPI inflation and oil price inflation, and one lag each of the CBO output gap and wage inflation. Our survey-based measure of short-run expected inflation is the mean 1-quarter ahead forecast of headline CPI inflation from the SPF. Our survey-based measures of long-run expected inflation are the mean 5-year ahead inflation forecast from the Michigan Survey of Consumers (MSC) and the mean 10-year ahead forecast of headline CPI inflation from the SPF. When estimating the NKPC with survey data, we add one lag of survey-expectations to the baseline instrument set noted above. Appendix A describes our data sources.

2.3 Estimation results

Table 2 reports the baseline parameter estimates from the four empirical specifications of the NKPC.[19] In Appendix E, we show that all of our main empirical findings are robust to changes in the inflation measure (use of core PCE inflation instead of core CPI inflation), changes in the measure of economic slack (use of detrended GDP instead of the CBO output gap), use of an alternative instrument set, and the exclusion of oil price inflation from the estimation.

Panel A in Table 2 shows that the estimated slope parameter $\widehat{\kappa}$ in the hybrid FIRE model is never statistically significant. Even worse, $\widehat{\kappa}$ exhibits the wrong sign in the first two subsamples. Galí and Gertler (1999) argue that labor's share of income should be used as the driving variable in the NKPC instead of the output gap. We repeat the estimation using labor's share of income in Appendix E.3 but still do not recover a statistically significant slope parameter. Our results for the hybrid FIRE model are consistent with previous findings in the literature, as surveyed by Mavroeidis, Plagborg-Møller, and Stock (2014).[20]

[19] The estimated oil price inflation coefficients are reported in Appendix E, Tables E1 and E2. All specifications pass J-tests of overidentifying restrictions. The J-test results are available upon request.

[20] These authors point to weak instruments as the main problem driving the results, potentially arising from using the lead term π_{t+1} as a regressor in the estimation of equation (8). A growing literature attempts to overcome weak identification problems by estimating the NKPC using regional data (Hooper, Mishkin, and

Table 2: Baseline NKPC parameter estimates

	Great Inflation Era 1960.q1 to 1983.q4	Great Moderation Era 1984.q1 to 2007.q3	Great Recession Era 2007.q4 to 2019.q2
	A. Hybrid FIRE[1]: $\widetilde{E}_t\pi_{t+1} = \gamma_f\, E_t\pi_{t+1} + \left(1-\gamma_f\right)\pi_{t-1}$		
$\widehat{\kappa}$	-0.013	-0.003	0.010
	(0.019)	(0.010)	(0.013)
$\widehat{\gamma}_f$	0.862***	1.003***	0.743***
	(0.123)	(0.179)	(0.173)
	B. Accelerationist: $\widetilde{E}_t\pi_{t+1} = \left(\pi_{t-1}+\pi_{t-2}+\pi_{t-3}+\pi_{t-4}\right)/4$		
$\widehat{\kappa}$	0.080***	0.033***	0.020***
	(0.022)	(0.010)	(0.010)
	C. Imperfect information: $\widetilde{E}_t\pi_{t+1} = \widetilde{E}_{t-1}\pi_t + \lambda(\pi_t - \widetilde{E}_{t-1}\pi_t)$		
$\widehat{\kappa}$	0.066***	0.042***	0.063***
	(0.115)	(0.015)	(0.013)
$\widehat{\lambda}$	0.280***	0.119**	0.008
	(0.021)	(0.059)	(0.010)
	D. Survey Data: $\widetilde{E}_t\pi_{t+1} = \widetilde{E}^s_t\pi_{t+h}$		
		1-q SPF	
$\widehat{\kappa}$		0.006	0.026**
		(0.020)	(0.011)
		5-y MSC[2]	
$\widehat{\kappa}$		0.024**	0.070***
		(0.011)	(0.015)
		10-y SPF[3]	
$\widehat{\kappa}$		0.041***	0.065***
		(0.010)	(0.019)
Obs.	96	95	47

Notes: The asterisks ***, **, and * denote significance at the 1, 5, and 10% levels, respectively. The estimation uses quarterly inflation rates (not annualized). Newey-West standard errors are shown in parentheses. [1]Due to the lead term π_{t+1}, the hybrid FIRE model uses one less observation of both y_t and π_t^{oil} in each subsample. [2]Great Moderation sample starts in 1990.q3. [3]Great Moderation sample starts in 1992.q1.

Sufi 2019, Fitzgerald, et al. 2020, Hazell, et al. 2022, and McLeay and Tenreyro 2020).

Panel B shows that $\widehat{\kappa}$ in the accelerationist model exhibits a clear downward trend over time. The estimated slope is quite steep during the Great Inflation Era ($\widehat{\kappa} = 0.08$) but it has since declined to level around 0.02 in the Great Recession Era. While the estimated slope parameter has declined over time, it remains statistically significant at the 1 percent level in all three subsamples. The accelerationist model has no way of accounting directly for shifts in the degree of expectations anchoring. Rather, the degree of anchoring is captured only indirectly via the behavior of lagged inflation over the past four quarters.

Panel C shows that $\widehat{\kappa}$ in the imperfect information model remains stable and highly statistically significant across all three subsamples. But in contrast, the estimated value of the gain parameter $\widehat{\lambda}$ declines over time, going from around 0.3 during the Great Inflation Era to around 0.1 during the Great Moderation Era. In the Great Recession Era, $\widehat{\lambda}$ is not statistically different from zero. According to the imperfect information model, a decline in the gain parameter implies that expected inflation has become more firmly anchored. The estimated values of $\widehat{\kappa}$ from our imperfect information model are relatively large compared to other estimates in the literature (see Hazell, et al. 2022 for an overview).

The hybrid RE model implies that the Phillips curve always been flat whereas the accelerationist model implies that the curve has become flatter over time. The imperfect information model implies that the Phillips curve slope has remained approximately constant. Which of these conclusions is correct? To help address this question, we estimate the NKPC using direct measures of expected inflation from surveys. Panel D in Table 2 reports estimation results using survey-based measures of expected inflation for the Great Moderation Era and the Great Recession Era.[21]

In Panel D, all three survey-based measures of expected inflation deliver a highly statistically significant slope parameter in the most recent subsample. Moreover, the values of $\widehat{\kappa}$ all increase when going from the Great Moderation Era to the Great Recession Era. These results contradict notions that the NKPC has always been flat or that it has become flatter over time. If anything, the results suggest that the NKPC has become steeper over time.

Panel D further shows that the Phillips curve relationship in the data is substantially stronger when longer-run expected inflation is used in the estimation. Notably, when we use the 10-year ahead inflation forecast from the SPF, the resulting values of $\widehat{\kappa}$ are nearly identical to those obtained from the imperfect information model.[22] This result suggests that the forecast rule (6) captures the behavior of long-term inflation expectations in survey data.

[21] The survey-based measures are not available for the Great Inflation Era.

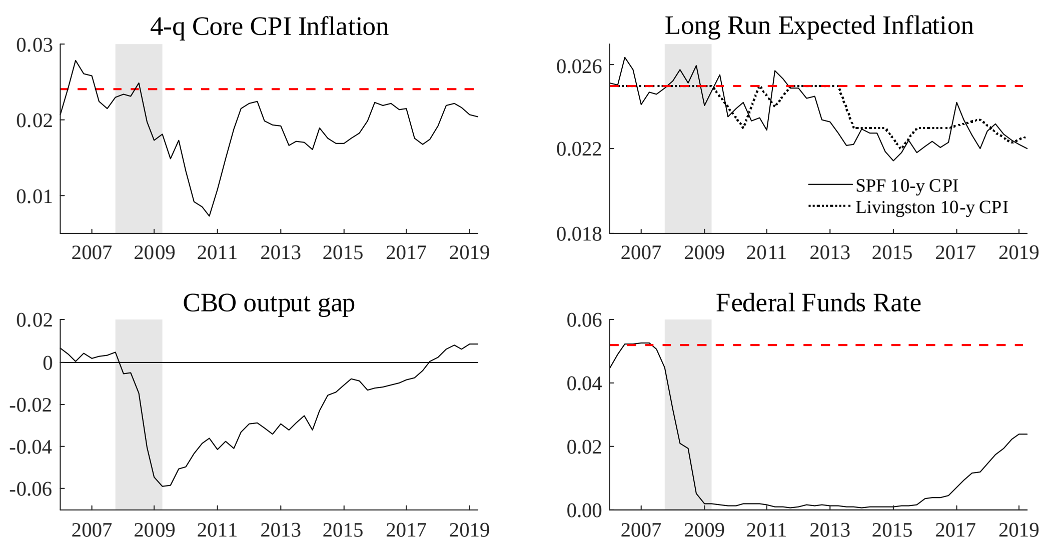
[22] As we demonstrate later, the New Keynesian model that motivates the forecast rule (6) implies that the optimal inflation forecast is approximately the same for all future horizons.

Overall, the results in Table 2 do not support the idea that the NKPC has become structurally flatter over time.

3 Resolving the inflation puzzles

In this section, we show that the imperfect information version of the NKPC can account for the "puzzling" behavior of inflation observed since 2007.

Figure 2: *Key macroeconomic variables 2006.q1 to 2019.q2*



Notes: Gray bars indicate the Great Recession from 2007.q4 to 2009.q2. Dashed red lines indicate pre-recession levels as measured by the average level of each variable over the four quarters prior to the start of recession, i.e., from 2006.q4 to 2007.q3. Data sources are described in Appendix A

Figure 2 shows the evolution of key macroeconomic variables from 2006 onward. During the Great Recession from 2007.q4 to 2009.q2, the output gap estimated by the Congressional Budget Office (CBO) declined by around 6 percentage points. From a historical perspective, a recession of this magnitude should have delivered substantial disinflationary pressures. But in the wake of the Great Recession, core Consumer Price Index (CPI) inflation declined by less than 2 percentage points. The absence of a persistent decline in inflation during the Great Recession has been labeled "the missing disinflation puzzle." (Coibion and Gorodnichenko 2015a). Figure 2 shows that long-run expected inflation, as measured by 10-year ahead forecasts of CPI inflation from either the SPF or the Livingston Survey, remained nearly constant during the Great Recession. In the aftermath of the recession, however, long-run expected inflation from surveys gradually declined; the end-of-sample values in Figure 2 are about 25 basis points (bp) below their pre-recession levels. Similarly, core CPI inflation in 2019 is about 50 bp below its pre-recession level. The absence of re-inflation during the recovery from the Great Recession has been labeled the "missing inflation puzzle" (Constâncio 2015).

To show that our imperfect information model can account for the inflation puzzles in Figure 2, we re-estimate the three versions of the NKPC in Panels A, B and C of Table 2 using data from 1999.q1 to 2007.q3. As shown in Appendix D.1, the date 1999.q1 is approximately when the anchoring process for expected inflation appears to have been completed. Others reach similar conclusions regarding the timing of the anchoring process (Mishkin 2007, Bernanke 2007, Goldstein 2021, and Carvalho, et al. 2023).

The NKPC estimates for the inflation-prediction exercise are shown in Table 3. The point estimates are broadly similar to those in Table 2 for the Great Recession Era.[23]

Figure 3 plots the model-implied paths for inflation starting in 2007.q4 from the three NKPC versions along with the 95% confidence bands. For this exercise, we use the CBO output gap as the only driving variable.[24] For the hybrid FIRE model, we construct the inflation-prediction using the closed-form solution of equation (8) and assume perfect foresight with respect to future values of the driving variable y_t.[25]

The predicted inflation rate from the hybrid FIRE model exhibits very wide confidence bands compared to the other two models. Conditional on the path of the CBO output gap, one cannot statistically reject deflation rates in the neighborhood of -20% during the Great Recession. Put another way, the hybrid FIRE model is largely uninformative about the path for inflation.[26]

The confidence bands surrounding the accelerationist model's inflation path are much narrower, reflecting the high precision of the $\widehat{\kappa}$ estimate in Table 3. But the accelerationist model predicts a pronounced deflation episode during and after the Great Recession; model-implied inflation declines by around 7 percentage points between 2007.q4 and 2019.q2.

[23] The full set of estimates for the period 1999.q1 to 2007.q3, including the oil price inflation coefficients, are provided in Appendix D.2, Table D1.

[24] Specifically, we drop the oil price inflation terms from the three estimated versions of the NKPC. In Appendix D.4, we show that including oil price inflation as an additional driving variable in the inflation-prediction exercise does not significantly improve the imperfect information model's ability to resolve the inflation puzzles.

[25] Our methodology is described in detail in Appendix D.3. The assumption of perfect foresight ensures that perfectly informed rational agents do not make systematic forecast errors with respect to the driving variable.

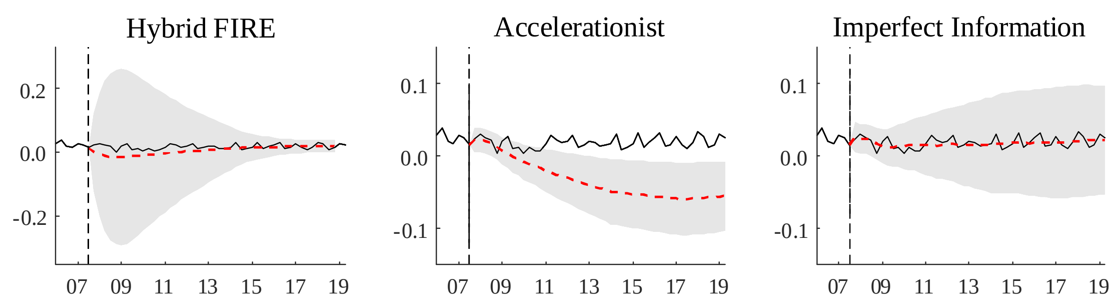
[26] The confidence bands begin to narrow from 2009.q3 onward because the CBO output gap starts to recover.

Table 3: NKPC estimates for model-predicted inflation

	Hybrid FIRE	Accelerationist	Imperfect information
$\widehat{\kappa}$	0.002	0.046***	0.048***
	(0.009)	(0.012)	(0.019)
$\widehat{\gamma}_f$	0.636***	–	–
	(0.101)		
$\widehat{\lambda}$	–	–	0.024
			(0.177)

Notes: The asterisks ***, **, and * denote significance at the 1, 5, and 10% levels, respectively. The estimation uses quarterly inflation rates (not annualized). Newey-West standard errors are shown in parentheses. The estimation period is 1999.q1 to 2007.q3.

Figure 3: *Model-predicted inflation: 2007.q4 to 2019.q2*

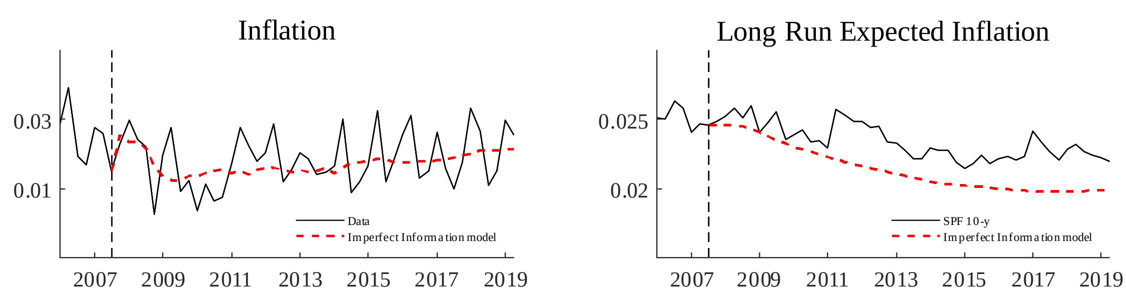


Notes: Gray areas indicate 95% confidence bands. Model-predicted paths for inflation are expressed as annualized quarterly rates.

In contrast with the other two models, the predicted inflation path from the imperfect information model is closely aligned with the data. Figure 4 provides a close-up view of the results together with a comparison between the model's path for expected inflation and the path of long-run expected inflation from the SPF. Despite the imperfect information model's relatively large estimated slope parameter ($\widehat{\kappa} = 0.048$), model-predicted inflation declines by only about 1 percentage point during the Great Recession. This modest decline is followed by persistently low inflation rates, consistent with the data. By the end of the simulation in 2019.q2, the predicted inflation rate is around 40 bp below its pre-recession level. Thus, according to the imperfect information model, there is no missing disinflation during the Great Recession and no missing inflation during the subsequent recovery.

The right panel of Figure 4 shows that the imperfect information model accurately captures the behavior of long-run expected inflation in the SPF. Expected inflation in the imperfect information model is computed from equation (5) using model-predicted inflation as the input. As noted earlier, a low value of the estimated gain parameter $\widehat{\lambda}$ (implying well-anchored inflation expectations) implies a low sensitivity of inflation to the output gap and low inflation persistence. This feature of the imperfect information model explains the absence of a persistent decline in inflation during the Great Recession. However, because inflation expectations are not perfectly anchored ($\widehat{\lambda} = 0.024 > 0$), the model-predicted path for long-run expected inflation will gradually decline when inflation remains persistently low. While the decline in long-run expected inflation is modest (around 50 bp in the model and 25 bp in the SPF), it is highly persistent. The low level of expected inflation in the imperfect information model serves to keep actual inflation low, even after the CBO output gap has fully recovered. This feature allows the imperfect information model to account for the "missing inflation" during the recovery from the Great Recession.

Figure 4: *Model-predicted inflation and expected inflation: 2007.q4 to 2019.q2*



Notes: Model-predicted paths for inflation and expected inflation in the imperfect information model. These are expressed as annualized quarterly rates. Expected inflation is computed from equation (6) using model-predicted inflation as the input. Inflation in the data is the annualized quarterly core CPI inflation rate. Long-run expected inflation in the data is the 10-year ahead forecast of headline CPI inflation from the Survey of Professional Forecasters.

4 Policy and anchored expectations in equilibrium

Many economists believe that the start of the expectations anchoring process can be traced to a shift in monetary policy under Fed Chairman Paul Volcker in the early-1980s. Indeed, at the peak of the Great Inflation, Volcker himself (1979, pp. 888-889) emphasized the crucial importance of inflation expectations: *"Inflation feeds in part on itself, so part of the job of returning to a more stable and more productive economy must be to break the grip of inflationary expectations."*

In this section, we use a New Keynesian model to show that a shift towards a more hawkish monetary policy regime can serve to endogenously anchor agents' inflation expectations. Improved anchoring allows the theoretical model to explain the observed changes in U.S. inflation behavior, as summarized in Table 1. These changes include: (1) the flattening of the accelerationist Phillips curve, (2) the steepening of the original Phillips curve, (3) the decline in inflation volatility, and (4) the decline in inflation persistence.

4.1 A Simple New Keynesian model

Along the lines of McLeay and Tenreyro (2020), we employ a New Keynesian model consisting of the NKPC (1), and the following targeting rule for monetary policy:

$$y_t = -\kappa\mu_\pi \left(\pi_t - \pi_t^*\right) + v_t, \qquad \mu_\pi > 0, \;\; v_t \sim N\left(0, \sigma_v^2\right), \tag{14}$$

where v_t is an *iid* shock that is uncorrelated with other shocks and π_t^* is the (possibly) time-varying inflation target of the central bank. Equation (14) is the optimal targeting rule under discretion, where the parameter μ_π is the weight on inflation stabilization relative to output gap stabilization in the central bank's loss function. The shock v_t can be viewed as an implementation error. The case when $\mu_\pi \to \infty$ corresponds to "strict inflation targeting."

As in previous literature (Erceg and Levin 2003, Ireland 2007, Cogley, et. al 2010), we abstract from the central bank's choice of the inflation target but instead postulate that π_t^* is governed by the following stochastic process:

$$\pi_t^* = \rho\pi_{t-1}^* + \varepsilon_t, \qquad 0 < \rho < 1, \;\; \varepsilon_t \sim N\left(0, \sigma_\varepsilon^2\right), \tag{15}$$

where ε_t is an *iid* shock and ρ is an autoregressive coefficient. As in most of the literature, we assume the inflation target follows a near-unit root process in deviations from its constant steady state value, setting $\rho \simeq 1$.

4.2 Expectations

4.2.1 Full information

The model consists of the NKPC (1), the targeting rule (14) and the law of motion for π_t^* (15). Under full information rational expectations (FIRE), the agent's inflation forecast is given by

$$E_t \pi_{t+1} = \frac{\kappa^2 \mu_\pi \rho}{1 + \kappa^2 \mu_\pi - \beta\rho} \pi_t^*, \tag{16}$$

which shows that $E_t \pi_{t+1} \simeq \pi_t^*$ when $\beta \simeq 1$ and $\rho \simeq 1$.

4.2.2 Imperfect information

Under imperfect information, we assume that private-sector agents cannot directly observe π_t^*. Instead, as in Erceg and Levin (2003), they solve a signal extraction problem to infer π_t^* from observable data. Following Svensson and Woodford (2003), we further assume that agents cannot directly observe the output gap y_t. Instead, conditional on observing π_t and their own inflation forecast $\widetilde{E}_t \pi_{t+1}$, private-sector agents use equations (1), (14) and (15) to construct an optimal estimate of π_t^* each period.

As shown in Appendix F, the optimal inflation forecast under imperfect information is given by:

$$\widetilde{E}_t \pi_{t+1} = \frac{\kappa^2 \mu_\pi \rho}{1 + \kappa^2 \mu_\pi - \beta\rho} \widetilde{E}_t \pi_t^*, \tag{17}$$

where $\widetilde{E}_t \pi_t^*$ is the current Kalman filter estimate of π_t^*. The expectations operator $\widetilde{E}_t$ represents the conditional expectation based on information available to private-sector agents in period t.

The current Kalman-filter estimate $\widetilde{E}_t \pi_t^*$ is given by:

$$\widetilde{E}_t \pi_t^* = \frac{1 + \kappa^2 \mu_\pi - \beta\rho}{1 + \kappa^2 \mu_\pi - \beta\rho(1 - \lambda_\pi)} \left[\frac{\lambda_\pi (1 + \kappa^2 \mu_\pi)}{\kappa^2 \mu_\pi} \pi_t + (1 - \lambda_\pi) \widetilde{E}_{t-1} \pi_t^* \right], \tag{18}$$

where λ_π is the steady state Kalman gain. The value of λ_π that minimizes the mean-squared forecast error for π_{t+1} is given by:

$$\lambda_\pi = \frac{-\phi - (1 - \rho^2) + \sqrt{(\phi + 1 - \rho^2)^2 + 4\phi\rho^2}}{2\rho^2}, \tag{19}$$

where $\phi \equiv \sigma_\varepsilon^2 / \left[(\kappa^2 \sigma_v^2 + \sigma_u^2) / (\kappa^2 \mu_\pi)^2 \right]$ is the signal-to-noise ratio.[27]

[27] The solution to the filtering problem employed here follows Gourinchas and Tornell (2004) and Gilchrist and Saito (2008). For additional details regarding the Kalman filter, see Hamilton (1994, Ch. 13).

In the analysis that follows, we assume $\beta \simeq 1$ and $\rho \simeq 1$, which simplifies the various expressions. In this case, equations (17) and (18) map directly to the inflation forecast rule (6) that we employed earlier in the NKPC estimation exercise. The forecast rule gain parameter λ is given by:

$$\lambda \equiv \frac{\lambda_\pi \left(1+\kappa^2 \mu_\pi\right)}{\lambda_\pi + \kappa^2 \mu_\pi}, \tag{20}$$

which shows that the value of λ increases as λ_π increases.[28]

As $\phi \to \infty$, we have $\lambda_\pi \to 1$ from equation (19) and $\lambda \to 1$ from equation (20). A high signal-to-noise ratio implies that inflation is driven mostly by the persistent inflation target shock ε_t. Consequently, the current Kalman filter estimate $\widetilde{E}_t \pi_t^*$ will be revised by a large amount in response to the most recent forecast error. In contrast, a low signal-to-noise ratio implies that inflation is driven mostly by the transitory shocks, v_t and u_t, yielding a low value of λ. As $\phi \to 0$, we have $\lambda_\pi \to 0$ and $\lambda \to 0$. In this case, $\widetilde{E}_t \pi_t^*$ is not revised at all in response to the most-recent forecast error. This latter case corresponds to the definition of "anchored" expectations provided by Bernanke's (2007).

In the two special cases when $\phi \to \infty$ (inflation driven exclusively by the inflation target shock) or when $\phi \to 0$ (inflation driven exclusively by transitory shocks), the imperfect information forecast implied by equations (17) and (18) coincides with the full information forecast (16). Intuitively, the agent can perfectly extract the central bank's actual inflation target if there are no noise shocks ($\phi \to \infty$) or if the actual target is constant ($\phi \to 0$).

With a constant inflation target, inflation expectations will become perfectly anchored in steady state such that $\lambda \to 0$. But out-of steady state, inflation expectations can be imperfectly anchored even when the central bank's inflation target is constant. In the following sections, we examine the implications of improved anchoring in an environment where the central bank's actual inflation target is constant.

4.3 Anchored expectations and the reduced form Phillips curve

In this section, we examine how improved anchoring of expected inflation can influence the slopes of reduced form Phillips curve relationships and the various inflation moments listed in Table 1. To build intuition, we first focus on the model's *conditional* moments in response to an *iid* demand shock v_t. In the next section, we demonstrate quantitatively that all of our findings hold for the unconditional moments implied by the model.

[28] Enforcing the link between λ and κ implied by equation (20) in our NKPC estimation exercise does not change any of our empirical findings. This is because any resulting variation in λ can be absorbed by variation in λ_π .

4.3.1 Conditional moments with full information

As before, we assume $\beta \simeq 1$ and $\rho \simeq 1$. Conditional on a demand shock, it is straightforward to derive the following expressions from the full information model:

$$\frac{Cov\left(\Delta\pi_t, y_t\right)_{v,E}}{Var\left(y_t\right)_{v,E}} = \kappa, \tag{21}$$

$$\frac{Cov\left(\pi_t, y_t\right)_{v,E}}{Var\left(y_t\right)_{v,E}} = \kappa, \tag{22}$$

$$Std.\ Dev.\left(\pi_t\right)_{v,E} = \frac{\kappa}{1+\kappa^2\mu_\pi}\,\sigma_v, \tag{23}$$

$$Corr\left(\pi_t, \pi_{t-1}\right)_{v,E} = 0, \tag{24}$$

$$\frac{Cov\left[\left(\pi_t - E_t\pi_{t+1}\right), y_t\right]_{v,E}}{Var\left(y_t\right)_{v,E}} = \kappa, \tag{25}$$

where the subscript "v, E" denotes the conditional moments in response to a demand shock v_t under the assumption of full information such that $\widetilde{E} = E$. Under full information, the slope of the accelerationist Phillips curve (21) and the slope of the original Phillips curve (22) are both equal to the true structural slope parameter κ in the NKPC. Also, there is no intrinsic persistence in the model such that $Corr\left(\pi_t, \pi_{t-1}\right)_{v,E} = 0$.

4.3.2 Conditional moments with imperfect information

Under imperfect information, inflation expectations are given by equations (17) and (18). With $\beta \simeq 1$ and $\rho \simeq 1$, we obtain the inflation forecast rule (6) that we employed in our NKPC estimation exercise of Section 2, with the gain parameter λ defined by equation (20). When $0 < \lambda < 1$, expected inflation $\widetilde{E}_t\pi_{t+1}$ is an exponentially-weighted moving average of current and past inflation rates. For analytical convenience here, we approximate expected inflation as $\widetilde{E}_t\pi_{t+1} \simeq \lambda\pi_{t-1}$. This simple specification inherits a key property of imperfectly anchored expectations, namely, that expected inflation (and hence inflation itself) exhibits excess persistence in response to a transitory shock. In the next section, we demonstrate quantitatively that all of our findings hold when expected inflation evolves according to the exact equations (17) and (18).

Conditional on a demand shock, the simplified imperfect information model implies the following reduced form slope coefficients and moments:

$$\frac{Cov\left(\Delta\pi_t, y_t\right)_{v,\widetilde{E}}}{Var\left(y_t\right)_{v,\widetilde{E}}} = \frac{\left(1+\kappa^2\mu_\pi\right)^2 - \lambda^2\left[1-\left(\kappa^2\mu_\pi\right)^2\frac{1-\lambda+\kappa^2\mu_\pi}{\lambda\kappa^2\mu_\pi}\right]}{\left(1+\kappa^2\mu_\pi\right)^2 - \lambda^2\left[1-\left(\kappa^2\mu_\pi\right)^2\right]}\ \kappa \geq \kappa, \tag{26}$$

$$\frac{Cov\left(\pi_t, y_t\right)_{v,\widetilde{E}}}{Var\left(y_t\right)_{v,\widetilde{E}}} = \frac{\left(1+\kappa^2\mu_\pi\right)^2 - \lambda^2\left(1+\kappa^2\mu_\pi\right)}{\left(1+\kappa^2\mu_\pi\right)^2 - \lambda^2\left[1-\left(\kappa^2\mu_\pi\right)^2\right]}\ \kappa \leq \kappa, \tag{27}$$

$$Std.\ Dev.\left(\pi_t\right)_{v,\widetilde{E}} = \frac{\kappa}{\sqrt{\left(1+\kappa^2\mu_\pi\right)^2 - \lambda^2}}\ \sigma_v, \tag{28}$$

$$Corr\left(\pi_t, \pi_{t-1}\right)_{v,\widetilde{E}} = \frac{\lambda}{1+\kappa^2\mu_\pi} \geq 0, \tag{29}$$

$$\frac{Cov\left[\left(\pi_t - \widetilde{E}_t\pi_{t+1}\right), y_t\right]_{v,\widetilde{E}}}{Var\left(y_t\right)_{v,\widetilde{E}}} = \kappa, \tag{30}$$

Equation (26) shows that imperfectly anchored inflation expectations induces an upward bias in the slope of the accelerationist Phillips curve relative to the true NKPC slope parameter κ. At the same time, equation (27) shows that there is a downward bias in the slope of the original Phillips curve relative to κ. Consequently, an econometrician cannot recover the value of κ from reduced form regressions when inflation expectations are imperfectly anchored.[29]

When $\lambda \to 0$ (perfect anchoring), equations (26) through (30) collapse to equations (21) through (25) from the full information model. Similarly, as $\mu_\pi \to 0$ (no weight on inflation stabilization in central bank loss function) the reduced form slope coefficients (26) and (27) collapse to their full information counterparts. Hence, the estimation biases in the reduced form slope coefficients relative to κ derive from imperfectly anchored inflation expectations coupled with an inflation-targeting central bank.

4.3.3 Propositions

From the preceding analysis, we can state the following propositions that summarize the effects of improved anchoring of expected inflation for reduced form Phillips curve slopes and inflation moments.

Proposition 1. *Anchored inflation expectations serve to reduce the estimated slope coefficient of the "accelerationist" Phillips curve, as measured by* $Cov\left(\Delta\pi_t, y_t\right)/Var\left(y_t\right)$, *in response to temporary demand or cost-push shocks.*

[29] Along these lines, Barnichon and Mesters (2021) find that controlling for cost-push shocks is not sufficient to recover a stable Phillips curve relationship because the reduced form slope coefficient can vary with the degree of anchoring of expected inflation.

Proof: From equations (21) and (26), we have:

$$\frac{Cov\left(\Delta\pi_t, y_t\right)_{v,E}}{Var\left(y_t\right)_{v,E}} = \kappa < \frac{Cov\left(\Delta\pi_t, y_t\right)_{v,\widetilde{E}}}{Var\left(y_t\right)_{v,\widetilde{E}}}$$

for all $0 < \lambda < 1$. A similar result can be derived conditional on a cost-push shock u_t. ■

Proposition 2. *Anchored inflation expectations serve to raise the estimated slope coefficient of the "original" Phillips curve, as measured by* $Cov\left(\pi_t, y_t\right)/Var\left(y_t\right)$, *in response to temporary demand or cost-push shocks.*
Proof: From equations (22) and (27), we have:

$$\frac{Cov\left(\pi_t, y_t\right)_{v,E}}{Var\left(y_t\right)_{v,E}} = \kappa > \frac{Cov\left(\pi_t, y_t\right)_{v,\widetilde{E}}}{Var\left(y_t\right)_{v,\widetilde{E}}}$$

for all $0 < \lambda \leq 1$. A similar result can be derived conditional on a cost-push shock u_t. ■

Proposition 3. *Anchored inflation expectations serve to reduce inflation volatility in response to temporary demand or cost-push shocks.*
Proof: From equations (23) and (28), we have:

$$Std.\ Dev.\left(\pi_t\right)_{v,E} < Std.\ Dev.\left(\pi_t\right)_{v,\widetilde{E}}$$

for all $0 < \lambda \leq 1$. A similar result can be derived conditional on a cost-push shock u_t. ■

Proposition 4. *Anchored inflation expectations serve to reduce inflation persistence, as measured by* $Corr\left(\pi_t, \pi_{t-1}\right)$, *in response to temporary demand or cost-push shocks.*
Proof: From equations (24) and (29), we have:

$$Corr\left(\pi_t, \pi_{t-1}\right)_{v,E} < Corr\left(\pi_t, \pi_{t-1}\right)_{v,\widetilde{E}}$$

for all $0 < \lambda \leq 1$. A similar result can be derived conditional on a cost-push shock u_t. ■

Proposition 5. *Using direct measures of expected inflation* $\widetilde{E}_t\pi_{t+1}$, *the true structural slope parameter of the NKPC* κ *can be recovered by regressing* $\pi_t - \widetilde{E}_t\pi_{t+1}$ *on* y_t *in response to a demand shock.*
Proof: The result follows directly from equation (30) for all $0 \leq \lambda \leq 1$. ■

Propositions 1 and 2 show that improved anchoring of expected inflation can explain the flattening of the accelerationist Phillips curve and the steepening of the original Phillips curve, as has occurred in U.S. data. Intuitively, because imperfectly anchored inflation expectations depend on past inflation, a temporary positive demand shock or cost push shock generates a persistent rise in expected inflation and hence a persistent rise in actual inflation. An inflation-targeting central bank responds to the persistent rise in inflation by reducing the output gap, thereby generating negative co-movement between π_t and y_t. This leads to a downward bias in the slope of the original Phillips curve relative to κ. The same mechanism generates an upward bias in the slope of the accelerationist Phillips curve slope relative to κ. To see this, we can combine the NKPC (1) with $\beta \simeq 1$ and $\widetilde{E}_t \pi_{t+1} \simeq \lambda \pi_{t-1}$ to yield the following expressions:

$$\pi_t = \lambda \pi_{t-1} + \kappa y_t + u_t, \tag{31}$$

$$\Delta \pi_t = -(1-\lambda)\,\pi_{t-1} + \kappa y_t + u_t. \tag{32}$$

Equation (31) shows that π_t depends positively on π_{t-1} (through expected inflation), whereas equation (31) shows that $\Delta \pi_t$ depend *negatively* on π_{t-1}. Thus, if monetary policy generates negative co-movement between π_{t-1} and y_t, then there will also be negative co-movement between π_t and y_t but positive co-movement between $\Delta \pi_t$ and y_t. These co-movement patterns serve to increase the slope of the accelerationist Phillips curve relative to the slope of original Phillips curve when inflation expectations are imperfectly anchored. But as anchoring improves, the slope of the accelerationist Phillips curve will decline relative to the slope of original Phillips curve. This is exactly what has occurred in U.S. data.

Propositions 3 and 4 show that improved anchoring can also explain the reduction in inflation volatility and persistence observed in U.S. data, as documented in Table 1. Intuitively, imperfectly anchored inflation expectations generates excess volatility and persistence of inflation in response to temporary shocks. As anchoring improves, these effects are diminished.

Proposition 5 shows that an econometrician can recover the true NKPC slope parameter κ by using direct measures of expected inflation $\widetilde{E}_t \pi_{t+1}$ (for example from surveys) and then regressing $\pi_t - \widetilde{E}_t \pi_{t+1}$ on y_t in response to demand shocks.

In the next section, we demonstrate quantitatively that improved anchoring of expected inflation enables the model to account for all of the stylized facts in Table 1. We also demonstrate that a reduction in the NKPC slope parameter κ or, alternatively, a stronger monetary response to inflation (as proposed by Bullard 2018 and McLeay and Tenreyro 2020) cannot account for several of these facts.

4.3.4 Calibration

We consider a standard calibration of the model using the parameter values shown in Table 4. We set $\beta = 0.995$, implying a steady state annual real interest rate of 2 percent. We set $\kappa = 0.06$, which roughly corresponds to the average estimated NKPC slope parameter for the imperfect information model, as shown in Table 2. As a baseline, we set the targeting rule coefficient on inflation to $\mu_\pi = 2$. The shock volatility measures σ_v and σ_u are set to 0.50 percent and 0.20 percent, respectively. These values allow the model to match the standard deviation of core CPI inflation as well as the reduced form slope coefficient $Cov\left(\pi_t, y_t\right)/Var\left(y_t\right)$ from Table 1 in the post 1999-subsample.[30] We set $\rho = 0.99$, implying that the actual inflation target π_t^* is highly persistent. The standard deviation of the inflation target shock is set to $\sigma_\varepsilon = 0$, implying that the actual inflation target is constant. We view this as a reasonable characterization of U.S. monetary policy during the post-Volcker period.

Table 4: Baseline parameter values

Parameter	Value	Description
β	0.995	Subjective time discount factor.
κ	0.06	Slope parameter in NKPC.
μ_π	2	Relative policy weight on inflation stabilization
ρ	0.99	Persistence of inflation target shock
σ_v	0.5	Std. dev. of demand shock in percent.
σ_u	0.2	Std. dev. of cost-push shock in percent.
σ_ε	0	Std. dev. of inflation target shock in percent.

4.3.5 Quantitative effects of improved anchoring in full model

To capture the effects of improved anchoring over time, we use the out-of-steady state version of the Kalman gain formula, as given by:

$$\lambda_{\pi,t} = \frac{\rho^2 \lambda_{\pi,t-1} + \phi}{1 + \rho^2 \lambda_{\pi,t-1} + \phi}. \tag{33}$$

Equation (33) delivers the steady state Kalman gain formula (19) when $\lambda_{\pi,t} = \lambda_\pi$ for all t.[31] Given $\lambda_{\pi,t}$, expected inflation evolves according to equations (17) and (18).

When π_t^* is constant, we have $\sigma_\varepsilon = 0$ such that $\phi = 0$. In this case, expected inflation is perfectly anchored in steady state such that $\lambda_\pi = 0$, implying $\lambda = 0$ from equation (20). However, in the transition towards the steady state, the Kalman gain will evolve according to

[30] From Table 1, these moments are $Std.\ Dev.\left(4\pi_t\right) = 0.80\%$ and $Cov\left(\pi_t, y_t\right)/Var\left(y_t\right) = 0.04$.

[31] See Gourinchas and Tornell (2004).

equation (33).[32] We start from an initial condition $\lambda_{\pi,0} > 0$. Intuitively, initial expectations may be imperfectly anchored because the actual inflation target was not constant in the past. But as time evolves, $\lambda_{\pi,t}$ will converge towards zero, implying improved anchoring. Given the time-varying value of $\lambda_{\pi,t}$, we compute a time-varying value of λ_t from the definition (20). We calibrate the initial value $\lambda_{\pi,0}$ to obtain $\lambda_0 = 0.54$. As our calibration sets $\beta \simeq 1$ and $\rho \simeq 1$, this initial value corresponds to the largest estimated gain value from our NKPC estimations in Section 2.[33] We set the agent's prior $\widetilde{E}_0 \pi_1^*$ in equation (18) to 4 percent, which corresponds to the observed value of quarterly CPI inflation (not annualized) at the peak of the Great Inflation Era in 1980.q1. None of our conclusions depend on the value of $\widetilde{E}_0 \pi_1^*$. All other parameters take on the values shown in Table 4.

Starting from $\lambda_0 = 0.54$, the top left panel of Figure 5 plots the model-implied path for λ_t. Convergence to the vicinity of the steady state takes around 100 quarters. The time to complete the anchoring process in the model is roughly consistent with the U.S. experience, as implied by our empirical results in Section 2. As λ_t approaches zero, expectations become perfectly anchored and the imperfect information equilibrium converges to the full information equilibrium. The remaining panels of Figure 5 plot moments computed using a 80 quarter (20-year) centered moving window of model-generated data, averaging over 50,000 simulations.

The declining trajectory of λ_t serves to reduce both inflation volatility and persistence, as measured by $Std.\ Dev. (4\pi_t)$ and $Corr(\pi_t, \pi_{t-1})$. At the same time, the decline in λ_t serves to reduce the slope coefficient $Cov(\Delta\pi_t, y_t)/Var(y_t)$, making the accelerationist Phillips curve flatter, while increasing the slope coefficient $Cov(\pi_t, y_t)/Var(y_t)$, making the original Phillips curve steeper.[34] Hence, the declining trajectory of λ_t allows the model to account for all of the stylized facts in Table 1.

4.3.6 Alternative explanations for the flatter Phillips curve

Figure 6 plots the effects of a decline in the true NKPC slope parameter κ (left panels) or an increase in the targeting rule weight on inflation μ_π (right panels). Neither experiment can

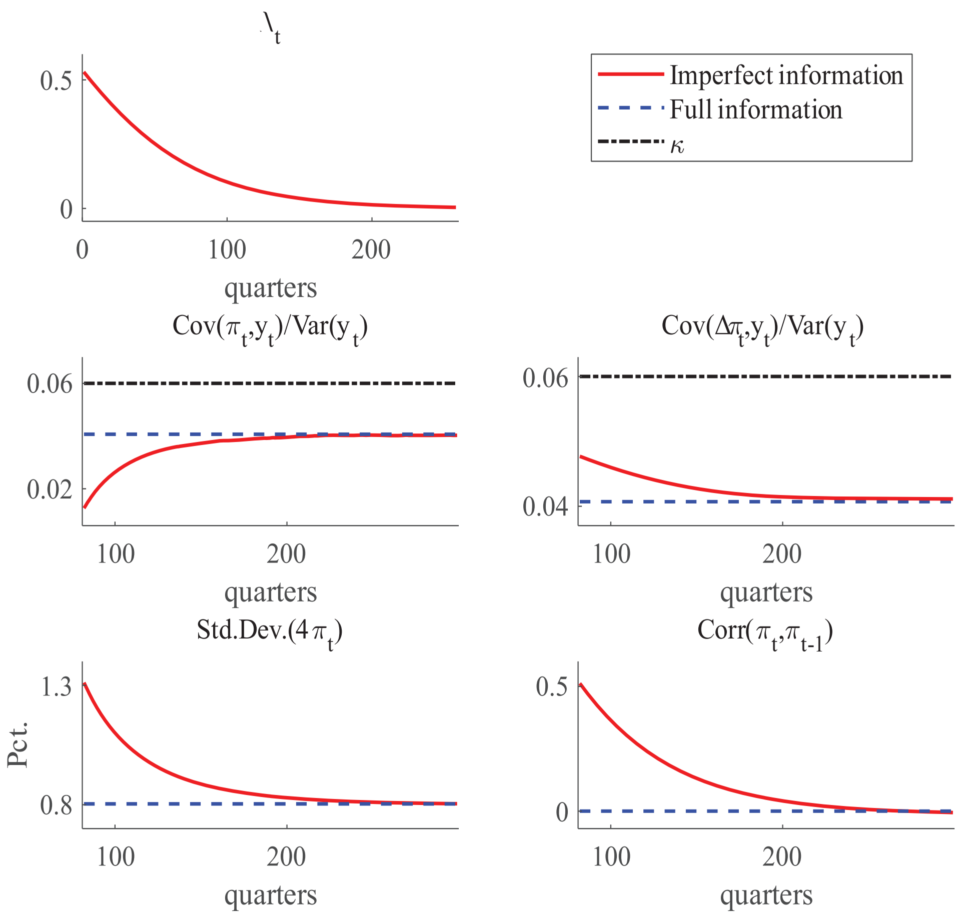
[32] Agents do not need to observe σ_u^2, σ_v^2 and σ_ε^2 to compute the signal-to-noise ratio ϕ. Along the lines of Lansing (2009), agents can compute the value of ϕ using moments of the observed data, namely, the autocorrelation of the first-difference of the observed signal.

[33] We obtain $\widehat{\lambda} = 0.54$ when we estimate the NKPC with imperfect information using core PCE inflation for the Great Inflation Era (see Table E.8 in Appendix E.5).

[34] All of the reduced form slope coefficients in Figure 5 are below the true NKPC slope coefficient κ. This is because the model simulation allows for cost-push shocks which induce a downward bias in the estimated slope coefficients, as emphasized by Bullard (2018) and McLeay and Tenreyro (2020).

account for the shifts in U.S. inflation behavior summarized in Table 1.[35] First, a change in either κ or μ_π has virtually no impact on inflation volatility or persistence.[36] Second, either a lower value of κ or a higher value of μ_π serves to reduce the slope of the original Phillips curve, which is not consistent with the U.S. data.

Figure 5: *The effects of anchored inflation expectations for model-implied moments*

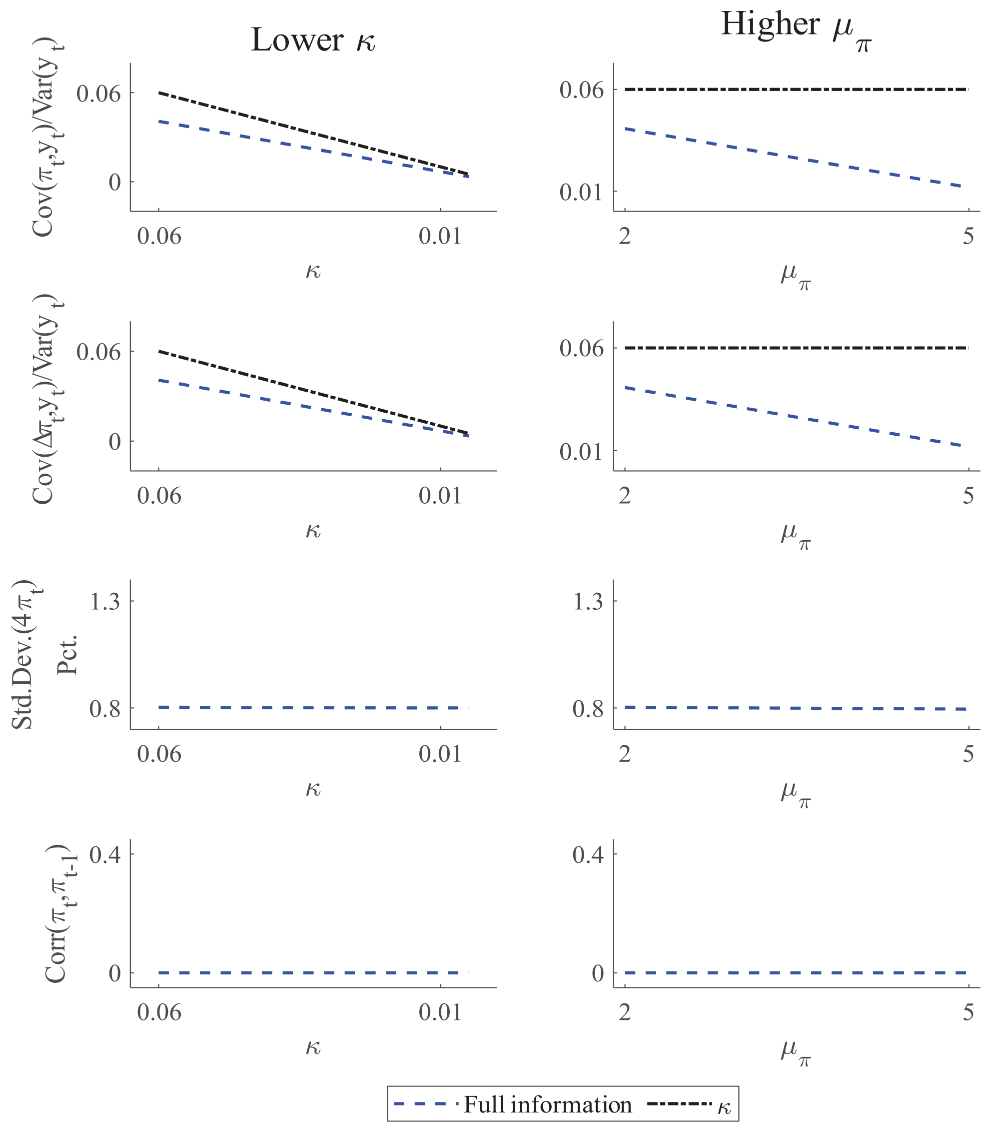


Note: The value of λ_t declines over time as the model converges to the steady state, thereby allowing the model to account for all of the stylized facts in Table 1.

[35] Here we abstract from changes in the degree of anchoring in the imperfect information model by setting $\lambda_t = \lambda = 0$. In this case, the imperfect information model coincides with the full information model.

[36] Extending the full information model with intrinsic sources of persistence, such as price indexation, would not change any of these conclusions.

Figure 6: *Effects of other parameter changes on model-implied moments*



Note: A lower value of κ or a higher value of μ_π both serve to reduce the slope of the original Phillips curve, which is not consistent with U.S. data.

5 Conclusion

According to conventional wisdom, the Phillips curve has become flatter in recent decades. But the meaning of "a flatter Phillips curve" is ambiguous because the phrase does not specify the form of the relationship between inflation and economic activity. We show that the statistical relationship between *changes* in inflation and economic activity, known as the accelerationist Phillips curve, has indeed become flatter. But in contrast, we show that the statistical relationship between the *level* of inflation and economic activity, which we refer to as the original Phillips curve, has become *steeper*. Over the same period, the volatility and persistence of U.S. inflation have both declined.

The observation of a stronger statistical relationship between inflation and economic activity is important because it contradicts some existing theories of a flatter Phillips curve. Using both empirical evidence and a theoretical model, we show that the improved anchoring of agents' inflation expectations provides a coherent explanation for the U.S. data.

First, we estimate a New Keynesian Phillips curve that allows for changes in the degree of anchoring of agents' inflation forecasts. The estimated structural slope parameter in the NKPC is highly statistically significant and stable over the period from 1960 to 2019. We obtain nearly identical estimated slope parameters using survey-based measures of long-run expected inflation, confirming that the structural Phillips curve relationship in the data is alive and well. Conditional on the actual path of the CBO output gap, our estimated NKPC can account for both the "missing disinflation puzzle" during the Great Recession and the "missing inflation puzzle" during the subsequent recovery.

Next, we propose a novel general equilibrium channel through which improved anchoring of expected inflation can help explain the observed changes in the reduced form Phillips curve relationships and inflation dynamics. In the context of a New Keynesian model with imperfect information, we show that imperfectly anchored expectations leads to excess inflation volatility and persistence. Coupled with an inflation-targeting central bank, excess inflation persistence induces a downward bias in the slope of the original Phillips curve but an upward bias in the slope of the accelerationist Phillips curve, relative to the true NKPC slope parameter. It follows that improved anchoring of expected inflation can help explain the flattening of the accelerationist Phillips curve, the steepening of the original Phillips curve, and the declines in inflation volatility and persistence observed in U.S. data. In contrast, neither a decline in the true NKPC slope parameter or an increase in the central bank's targeting rule weight on inflation can account for the patterns observed in the data.

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A Appendix: Data description

With the exception of the survey-based measures of expected inflation, all data series are from the Federal Reserve Economic Database (FRED) maintained by the Federal Reserve Bank of St. Louis. The series are described below with series names indicated in parentheses. Monthly data is converted into quarterly data by taking quarterly averages.

CBO output gap: 100*(GDPC1-GDPPOT)/GDPPOT, 100*(Bil. of Chn. 2012 $-Bil. of Chn. 2012 $)/Bil. of Chn. 2012 $, Quarterly (GDPC1_GDPPOT)

Core CPI index: Consumer price index for all urban consumers: All items less food and energy, monthly (CPILFENS, not seasonally adjusted, 1982-1984=100).

Core PCE index: Personal consumption expenditures: Chain-type price index less food and energy, quarterly (CPILFENS, seasonally adjusted, 2012=100).

Federal funds rate: Effective federal funds rate, pct., monthly (FEDFUNDS, not seasonally adjusted).

Labor share of income: Nonfarm business sector, labor share, quarterly, (PRS85006173, seasonally adjusted, Index 2012=100).

Unemployment rate: Unemployment rate: Aged 15-64: All Persons for the United States, pct., quarterly (LRUN64TTUSQ156N, not seasonally adjusted). We compute the unemployment gap by subtracting the natural rate of unemployment.

Natural rate of unemployment: Natural rate of unemployment (long-term), pct., quarterly (NROU, not seasonally adjusted).

Oil prices: Spot crude oil price, West Texas Intermediate (WTI), dollars per barrel, monthly, (WTISPLC, not seasonally adjusted).

Real GDP: Real gross domestic product, billions of chained 2012 dollars, quarterly (GDPC1, seasonally adjusted, 2012=100). We detrend real GDP using a two-sided Hodrick-Prescott filter with a smoothing parameter of 1600.

Wage index: Nonfarm business sector compensation per hour, quarterly (HCOMPBS, seasonally adjusted, 2012=100).

Survey-based expected inflation: The 1-quarter ahead and 10-year ahead mean CPI inflation forecasts are from the Survey of Professional Forecasters (quarterly).[37] The 5-year ahead mean inflation forecasts are from the Michigan Survey of Consumers (quarterly).[38] The 10-year ahead mean CPI inflation forecasts are from the Livingston Survey (semi-annual).[39]

[37] https://www.philadelphiafed.org/research-and-data/real-time-center/survey-of-professional-forecasters/data-files.

[38] https://data.sca.isr.umich.edu/data-archive/mine.php.

[39] https://www.philadelphiafed.org/research-and-data/real-time-center/livingston-survey/historical-data

B Appendix: Robustness of stylized facts

Tables B1 through B3 show that the stylized facts documented in Table 1 are robust to using alternative subsamples of U.S. data, an alternative inflation measure, or alternative measures of economic activity.

Table B1: Moments of U.S. inflation (Alternative subsamples)

	1960.q1 to 1983.q4	1984.q1 to 2019.q2
$Corr\left(\Delta\pi_t, y_t\right)$	0.14	0.05
$Cov\left(\Delta\pi_t, y_t\right)/Var\left(y_t\right)$	0.03	0.01
$Corr\left(\pi_t, y_t\right)$	−0.14	0.09
$Cov\left(\pi_t, y_t\right)/Var\left(y_t\right)$	−0.04	0.02
$Std.\ Dev.\left(4\pi_t\right)$	3.50	1.25
$Corr\left(\pi_t, \pi_{t-1}\right)$	0.75	0.63

Note: π_t is quarterly core CPI inflation, y_t is the CBO output gap, and $\Delta\pi_t = \pi_t - \pi_{t-1}$. Standard deviations are in percent.

Table B2: Moments of U.S. inflation (Alternative inflation measure)

	1960.q1 to 1998.q4	1999.q1 to 2019.q2
$Corr\left(\Delta\pi_t, y_t\right)$	0.21	0.01
$Cov\left(\Delta\pi_t, y_t\right)/Var\left(y_t\right)$	0.02	0.00
$Corr\left(\pi_t, y_t\right)$	−0.17	0.29
$Cov\left(\pi_t, y_t\right)/Var\left(y_t\right)$	−0.04	0.02
$Std.\ Dev.\left(4\pi_t\right)$	2.27	0.55
$Corr\left(\pi_t, \pi_{t-1}\right)$	0.92	0.29

Note: π_t is quarterly core PCE inflation, y_t is the CBO output gap, and $\Delta\pi_t = \pi_t - \pi_{t-1}$. Standard deviations are in percent.

Table B3: Moments of U.S. inflation (Alternative activity measures)

	1960.q1 to 1998.q4	1999.q1 to 2019.q2
$Corr\left(\Delta\pi_t, \widetilde{y}_t\right)$	0.16	0.03
$Cov\left(\Delta\pi_t, \widetilde{y}_t\right)/Var\left(\widetilde{y}_t\right)$	0.05	0.01
$Corr\left(\pi_t, \widetilde{y}_t\right)$	0.16	0.33
$Cov\left(\pi_t, \widetilde{y}_t\right)/Var\left(\widetilde{y}_t\right)$	0.07	0.06
$Corr\left(\Delta\pi_t, -u_t\right)$	0.24	0.00
$Cov\left(\Delta\pi_t, -u_t\right)/Var\left(u_t\right)$	0.09	0.00
$Corr\left(\pi_t, -u_t\right)$	-0.03	0.34
$Cov\left(\pi_t, -u_t\right)/Var\left(u_t\right)$	-0.01	0.04
$Corr\left(\Delta\pi_t, -U_t\right)$	0.23	0.00
$Cov\left(\Delta\pi_t, -U_t\right)/Var\left(U_t\right)$	0.08	0.00
$Corr\left(\pi_t, -U_t\right)$	-0.15	0.33
$Cov\left(\pi_t, -U_t\right)/Var\left(U_t\right)$	-0.07	0.04

Note: π_t is quarterly core CPI inflation, $\widetilde{y}_t$ is HP-filter detrended real GDP, u_t is the unemployment gap defined as the difference between the unemployment rate U_t and the natural rate of unemployment, and $\Delta\pi_t = \pi_t - \pi_{t-1}$.

C Relationship between expected inflation and economic activity

Table C.1 uses various measures of expected inflation from surveys and the CBO output gap to show that the value of $Cov(\widetilde{E}_t\pi_{t+h}, y_t)/Var\left(y_t\right)$ has *increased* over time in U.S. data. This observation is at odds with the anchoring mechanism proposed by Bernanke (2007) in which *"expectations respond less than previously to variations in economic activity."* The one-period ahead inflation forecast is the 1-quarter ahead CPI inflation forecast from the SPF (starting in 1981.q3). The 20-period ahead inflation forecast is the 5-year ahead inflation forecast from the Michigan Survey of Consumers (starting in 1990.q2). The 40-period ahead inflation forecast is the 10-year ahead CPI inflation forecast from the SPF (starting in 1991.q4).

Table C.1: The statistical relationship between expected inflation and economic activity

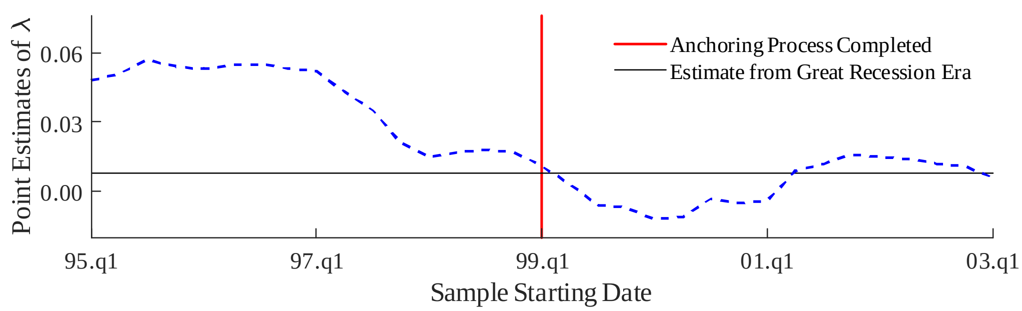
	Pre -1999.q1	1999.q1 to 2019.q2
$Cov\left(\widetilde{E}_t^s\pi_{t+1}, y_t\right)/Var\left(y_t\right)$	-0.06	0.04
$Cov\left(\widetilde{E}_t^s\pi_{t+20}, y_t\right)/Var\left(y_t\right)$	-0.09	0.00
$Cov\left(\widetilde{E}_t^s\pi_{t+40}, y_t\right)/Var\left(y_t\right)$	-0.07	0.00
$Corr\left(\widetilde{E}_t^s\pi_{t+1}, y_t\right)$	-0.40	0.67
$Corr\left(\widetilde{E}_t^s\pi_{t+20}, y_t\right)$	-0.85	0.02
$Corr\left(\widetilde{E}_t^s\pi_{t+40}, y_t\right)$	-0.92	0.06

D Appendix: Details of Model-Predicted Inflation

D.1 Timing of Anchoring Process

Figure 7 plots the point estimates of $\widehat{\lambda}$ from the imperfect information NKPC in Section 2 using a rolling series of sample start dates, but keeping the sample end date fixed at 2019.q2. Using 2019.q2 as the fixed sample end date instead of 2007.q3 yields more stable point estimates without changing the conclusions regarding the completion of the anchoring process. Figure 7 shows that from 1999.q1 onward, the estimated value of $\widehat{\lambda}$ fluctuates around the value obtained for the Great Recession Era. Thus, the anchoring process for expected inflation appears to have been completed around 1999.q1.

Figure 7: *Point estimates of the gain parameter for subsamples ending in 2019.q2*



Notes: The figure shows point estimates of the gain parameter $\widehat{\lambda}$ from the imperfect information NKPC using a rolling series of sample start dates, but keeping the sample end date fixed at 2019.q2. The anchoring process for expected inflation appears to have been completed around 1999.q1.

D.2 NKPC estimates for model-predicted inflation

Table D1: NKPC estimates for model-predicted inflation

	Hybrid FIRE	Accelerationist	Imperfect information
$\widehat{\kappa}$	0.002	0.046***	0.048***
	(0.009)	(0.012)	(0.019)
$\widehat{\delta}$	0.003	0.000	0.012**
	(0.003)	(0.004)	(0.006)
$\widehat{\varphi}$	−0.004*	−0.003**	−0.007**
	(0.003)	(0.002)	(0.004)
$\widehat{\gamma}_f$	0.636***	–	–
	(0.101)		
$\widehat{\lambda}$	–	–	0.024
			(0.177)

Notes: The asterisks ***, **, and * denote significance at the 1, 5, and 10% levels, respectively. The estimation uses quarterly inflation rates. (not annualized). Newey-West standard errors are shown in parentheses. Sample period is 1999.q1-2007.q3.

D.3 Predicted inflation in the hybrid FIRE model

The closed form solution of equation (8) can be written as:

$$\pi_t = \delta_1 \pi_{t-1} + \frac{\kappa}{\delta_2 \gamma_f} \sum_{k=0}^{T-1} \left(\frac{1}{\delta_2}\right)^k E_t y_{t+k} + E_t \left[\left(\frac{1}{\delta_2}\right)^T (\pi_{t+T} - \delta_1 \pi_{t+T-1}) \right], \tag{D.1}$$

where $\delta_1 = \frac{1-\sqrt{1-4(1-\gamma_f)\gamma_f}}{2\gamma_f}$ and $\delta_2 = \frac{1+\sqrt{1-4(1-\gamma_f)\gamma_f}}{2\gamma_f}$ are, respectively, the stable and unstable roots of the second order difference equation (8).

We assume perfect foresight and replace the expectations $E_t y_{t+k}$ and $E_t \pi_{t+k}$ with the realizations y_{t+k} and π_{t+k}, yielding:

$$\pi_t = \delta_1 \pi_{t-1} + \frac{\kappa}{\delta_2 \gamma_f} \sum_{k=0}^{T-1} \left(\frac{1}{\delta_2}\right)^k y_{t+k} + \left(\frac{1}{\delta_2}\right)^T (\pi_{t+T} - \delta_1 \pi_{t+T-1}), \tag{D.2}$$

where $T = 2019.q2$ is the final period of the simulation. Equation (D.2) shows that inflation at time t is a function of current and future realizations of y_{t+k} through 2019.q1 plus a terminal condition that depends on the realized inflation rates in 2019.q2 and 2019.q1.

D.4 Can oil prices help explain the missing disinflation puzzle?

Here we examine how movements in oil prices affect the predicted inflation path of the imperfect information version of the estimated NKPC. In a prominent paper, Coibion and Gorodnichenko (2015a) argue that the missing disinflation puzzle during the Great Recession can be explained by a rise in households' inflation expectations, which, in turn, can be traced to a simultaneous increase in oil prices. To evaluate this hypothesis within the context of the imperfect information NKPC, we construct the model-implied path for inflation using both the CBO output gap and oil price inflation as driving variables. As in the baseline prediction shown in Figures 3 and 4, the NKPC parameters are estimated using data from 1999.q1 to 2007.q3.

Table D2 compares the estimated oil price inflation coefficients for the imperfect information NKPC with the corresponding estimates using survey data. The left panel shows the results using data from 1999.q1 to 2007.q3 while the right panel shows the results using data from 2007.q4 to 2019.q2. Two observations are worth noting. First, the estimated oil price inflation coefficients for the imperfect information NKPC are very similar to those obtained using survey data. This result suggests that the imperfect information NKPC accurately captures the oil price pass-through to core CPI inflation implied by the survey data. Second, the estimated oil price inflation coefficients for the imperfect information NKPC are nearly the same across the two subsamples. This result suggests that oil price pass-through to core CPI inflation was similar in the years before and after the Great Recession.

Table D2: Estimated oil price inflation coefficients

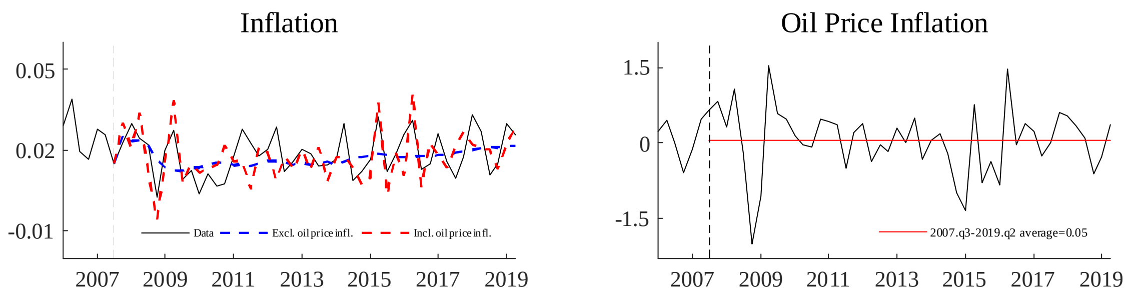
	Pre-Great Recession Period 1999.q1 to 2007.q3			Great Recession Era 2007.q4 to 2019.q2		
	Imperfect information	5-y MSC	10-y SPF	Imperfect information	5-y MSC	10-y SPF
$\widehat{\delta}$	0.012**	0.012*	0.008	0.016*	0.017*	0.023**
	(0.006)	(0.008)	(0.006)	(0.011)	(0.011)	(0.013)
$\widehat{\varphi}$	−0.007**	−0.005**	−0.006***	−0.005***	−0.005***	−0.006***
	(0.004)	(0.003)	(0.002)	(0.002)	(0.002)	(0.002)

Notes: The asterisks ***, **, and * denote significance at the 1, 5, and 10% levels, respectively. The estimation uses quarterly inflation rates (not annualized). Newey-West standard errors are shown in parentheses.

Figure 8 compares our baseline inflation-prediction from the imperfect information NKPC with an alternative simulation that uses realized oil price inflation as a driving variable in addition to the CBO output gap. Compared to the baseline prediction, the version that includes oil price inflation accounts quite well for the higher frequency movements in core CPI inflation since 2007. However, oil price inflation does not appear to be important in explaining the lower frequency movements in core CPI inflation since 2007.

The right panel of Figure 8 shows that oil price inflation exhibits very low persistence.[40] While average oil price inflation from 2007.q4 to 2019.q2 is around 5%, including it as a driving variable increases the average predicted CPI inflation rate by only 0.01 percentage points. These results show that including oil price inflation in the inflation-prediction exercise does not significantly improve the imperfect information NKPC's ability to account for the missing disinflation puzzle.

Figure 8: *Model-predicted inflation: The role of oil prices*



Notes: The left panel compares the baseline inflation path from the estimated imperfect information NKPC with an alternative model simulation that uses realized oil price inflation as a driving variable in addition to the CBO output gap. The right panel shows that oil price inflation exhibits very low persistence. Inflation is expressed as annualized quarterly rates.

[40] Oil price inflation is the annualized quarterly growth rate of the spot price for West Texas Intermediate crude oil. For details, see Appendix A.

E Appendix: Robustness of NKPC estimates

E.1 Baseline estimates: All coefficients

Table E1: Baseline NKPC estimates (1 of 2)

	Great Inflation Era 1960.q1 to 1983.q4	Great Moderation Era 1984.q1 to 2007.q3	Great Recession Era 2007.q4 to 2019.q2
	A. Hybrid FIRE[1]: $\widetilde{E}_t\pi_{t+1} = \gamma_f\, E_t\pi_{t+1} + \left(1-\gamma_f\right)\pi_{t-1}$		
$\widehat{\kappa}$	-0.013	-0.003	0.010
	(0.019)	(0.010)	(0.013)
$\widehat{\gamma}_f$	0.862***	1.003***	0.743***
	(0.123)	(0.179)	(0.173)
$\widehat{\delta}$	0.001	0.001	0.018
	(0.009)	(0.006)	(0.017)
$\widehat{\varphi}$	-0.003	-0.002	-0.003*
	(0.003)	(0.002)	(0.002)
	B. Accelerationist: $\widetilde{E}_t\pi_{t+1} = \left(\pi_{t-1}+\pi_{t-2}+\pi_{t-3}+\pi_{t-4}\right)/4$		
$\widehat{\kappa}$	0.080***	0.033***	0.020***
	(0.022)	(0.010)	(0.010)
$\widehat{\delta}$	-0.027*	-0.005	0.009**
	(0.020)	(0.005)	(0.005)
$\widehat{\varphi}$	0.026***	0.002	-0.004***
	(0.009)	(0.002)	(0.001)
	C. Imperfect information: $\widetilde{E}_t\pi_{t+1} = \widetilde{E}_{t-1}\pi_t + \lambda(\pi_t - \widetilde{E}_{t-1}\pi_t)$		
$\widehat{\kappa}$	0.066***	0.042***	0.063***
	(0.115)	(0.015)	(0.013)
$\widehat{\lambda}$	0.280***	0.119**	0.008
	(0.021)	(0.059)	(0.010)
$\widehat{\delta}$	-0.022*	-0.010*	0.016*
	(0.015)	(0.007)	(0.011)
$\widehat{\varphi}$	0.022***	0.003*	-0.005***
	(0.009)	(0.002)	(0.002)
Obs.	96	95	47

Notes: The asterisks ***, **, and * denote significance at the 1, 5, and 10% levels, respectively. The estimation uses quarterly inflation rates (not annualized). [1]Due to the lead term π_{t+1}, the hybrid FIRE model uses one less observation of both y_t and π_t^{oil} in each subsample. Newey-West standard errors are shown in parentheses.

Table E2: Baseline NKPC estimates (2 of 2)

	Great Inflation Era 1960.q1 to 1983.q4	Great Moderation Era 1984.q1 to 2007.q3	Great Recession Era 2007.q4 to 2019.q2
		D. Survey Data	
		1-q SPF	
$\widehat{\kappa}$		0.006	0.026**
		(0.020)	(0.011)
$\widehat{\delta}$		−0.016***	0.010
		(0.006)	(0.009)
$\widehat{\varphi}$		0.000	−0.006***
		(0.002)	(0.001)
$\widehat{c}$		0.000	0.000
		(0.000)	(0.000)
		5-y MSC[1]	
$\widehat{\kappa}$		0.024**	0.070***
		(0.011)	(0.015)
$\widehat{\delta}$		0.007*	0.017*
		(0.005)	(0.012)
$\widehat{\varphi}$		−0.004**	−0.005***
		(0.002)	(0.002)
$\widehat{c}$		−0.003***	−0.002***
		(0.000)	(0.000)
		10-y SPF[2]	
$\widehat{\kappa}$		0.041***	0.065***
		(0.010)	(0.019)
$\widehat{\delta}$		0.006	0.022**
		(0.005)	(0.013)
$\widehat{\varphi}$		−0.008***	−0.006***
		(0.002)	(0.002)
$\widehat{c}$		−0.001**	0.000
		(0.000)	(0.001)
Obs.	96	95	47

Notes: The asterisks ***, **, and * denote significance at the 1, 5, and 10 percent levels, respectively. The estimation uses quarterly inflation rates (not annualized). [1]Great Moderation subsample starts in 1990.q3. [2]Great Moderation subsample starts in 1992.q1. Newey-West standard errors are shown in parentheses.

E.2 Excluding oil price inflation

Table E3: NKPC estimates excluding oil price inflation.

	Great Inflation Era 1960.q1 to 1983.q4	Great Moderation Era 1984.q1 to 2007.q3	Great Recession Era 2007.q4 to 2019.q2
		A. Hybrid FIRE[1]: $\widetilde{E}_t \pi_{t+1} = \gamma_f \, E_t \pi_{t+1} + \left(1 - \gamma_f\right) \pi_{t-1}$	
$\widehat{\kappa}$	-0.009	-0.005	0.002
	(0.015)	(0.010)	(0.005)
$\widehat{\gamma}_f$	0.783***	0.978***	0.716***
	(0.149)	(0.170)	(0.075)
		B. Accelerationist: $\widetilde{E}_t \pi_{t+1} = \left(\pi_{t-1} + \pi_{t-2} + \pi_{t-3} + \pi_{t-4}\right)/4$	
$\widehat{\kappa}$	0.081***	0.030***	0.013*
	(0.018)	(0.009)	(0.010)
		C. Imperfect information: $\widetilde{E}_t \pi_{t+1} = \widetilde{E}_{t-1} \pi_t + \lambda(\pi_t - \widetilde{E}_{t-1} \pi_t)$	
$\widehat{\kappa}$	0.052***	0.034***	0.066***
	(0.017)	(0.013)	(0.010)
$\widehat{\lambda}$	0.346***	0.175**	0.000
	(0.108)	(0.083)	(0.005)
		D. Survey Data	
		1-q SPF	
$\widehat{\kappa}$		-0.005	0.042***
		(0.010)	(0.011)
$\widehat{c}$		0.000	0.001**
		(0.000)	(0.000)
		5-y MSC[2]	
$\widehat{\kappa}$		0.008	0.077***
		(0.012)	(0.013)
		-0.003***	-0.002***
		(0.000)	(0.000)
		10-y SPF[3]	
$\widehat{\kappa}$		0.020**	0.078***
		(0.011)	(0.010)
$\widehat{c}$		-0.001***	0.001**
		(0.000)	(0.000)
Obs.	96	95	47

Notes: The asterisks ***, **, and * denote significance at the 1, 5, and 10 percent levels, respectively. The estimation uses quarterly inflation rates (not annualized). Newey-West standard errors are shown in parentheses. [1]Due the lead term π_{t+1}, the hybrid FIRE model uses one less observation of y_t in each subsample. [2]Great Moderation subsample starts in 1990.q3. [3]Great Moderation subsample starts in 1992.q1.

E.3 Alternative driving variable: Labor share

Table E4: NKPC estimates using labor share (1 of 2)

	Great Inflation Era 1960.q1 to 1983.q4	Great Moderation Era 1984.q1 to 2007.q3	Great Recession Era 2007.q4 to 2019.q2
	A. Hybrid FIRE[1]: $\widetilde{E}_t\pi_{t+1} = \gamma_f\, E_t\pi_{t+1} + \left(1-\gamma_f\right)\pi_{t-1}$		
$\widehat{\kappa}$	0.042	−0.033	0.007
	(0.083)	(0.054)	(0.056)
$\widehat{\gamma}_f$	0.829***	1.040***	0.729***
	(0.108)	(0.210)	(0.166)
$\widehat{\delta}$	0.006	−0.006	0.016
	(0.015)	(0.013)	(0.014)
$\widehat{\varphi}$	−0.003	−0.000	−0.003**
	(0.003)	(0.003)	(0.002)
	B. Accelerationist: $\widetilde{E}_t\pi_{t+1} = \left(\pi_{t-1}+\pi_{t-2}+\pi_{t-3}+\pi_{t-4}\right)/4$		
$\widehat{\kappa}$	−0.097	0.025	0.051
	(0.136)	(0.052)	(0.062)
$\widehat{\delta}$	−0.012	−0.004	0.016*
	(0.019)	(0.006)	(0.012)
$\widehat{\varphi}$	0.017***	0.000	−0.005***
	(0.005)	(0.002)	(0.002)
	C. Imperfect information: $\widetilde{E}_t\pi_{t+1} = \widetilde{E}_{t-1}\pi_t + \lambda(\pi_t - \widetilde{E}_{t-1}\pi_t)$		
$\widehat{\kappa}$	0.002	0.169	0.049
	(0.177)	(0.161)	(0.082)
$\widehat{\lambda}$	0.118**	0.061*	0.096
	(0.055)	(0.044)	(0.153)
$\widehat{\delta}$	−0.001	−0.012*	0.019*
	(0.018)	(0.008)	(0.013)
$\widehat{\varphi}$	0.023***	0.003*	−0.005**
	(0.007)	(0.002)	(0.002)
Obs.	96	95	47

Notes: The asterisks ***, **, and * denote significance at the 1, 5, and 10 percent levels, respectively. The estimation uses quarterly inflation rates (not annualized). [1]Due to the lead term π_{t+1}, the hybrid FIRE model uses one less observation of both y_t and π_t^{oil} in each subsample. Newey-West standard errors are shown in parentheses..

Table E5: NKPC estimates using labor share (2 of 2)

	Great Inflation Era 1960.q1 to 1983.q4	Great Moderation Era 1984.q1 to 2007.q3	Great Recession Era 2007.q4 to 2019.q2
		D. Survey Data	
		1-q SPF	
$\widehat{\kappa}$		0.415	6.02
		(2.749)	(6.454)
$\widehat{\delta}$		-0.016^{***}	0.023
		(0.006)	(0.019)
$\widehat{\varphi}$		0.000	-0.007^{**}
		(0.002)	(0.004)
$\widehat{c}$		0.002	0.034
		(0.013)	(0.036)
		5-y MSC[1]	
$\widehat{\kappa}$		4.458^{**}	-8.676
		(2.110)	(9.507)
$\widehat{\delta}$		-0.001	0.015^{*}
		(0.005)	(0.010)
$\widehat{\varphi}$		0.000	-0.003
		(0.002)	(0.002)
$\widehat{c}$		0.018^{**}	-0.052
		(0.010)	(0.054)
		10-y SPF[2]	
$\widehat{\kappa}$		5.090	-2.547
		(4.423)	(3.945)
$\widehat{\delta}$		0.019^{**}	0.018^{*}
		(0.011)	(0.012)
$\widehat{\varphi}$		-0.006^{**}	-0.004^{**}
		(0.003)	(0.002)
$\widehat{c}$		0.024	-0.016
		(0.021)	(0.022)
Obs.	96	95	47

Notes: The asterisks ***, **, and * denote significance at the 1, 5, and 10 percent levels, respectively. The estimation uses quarterly inflation rates (not annualized). Newey-West standard errors are shown in parentheses. [1]Great Moderation subsample starts in 1990.q3. [2]Great Moderation subsample starts in 1992.q1.

E.4 Alternative driving variable: Detrended GDP

Table E6: NKPC estimates using detrended GDP (1 of 2)

	Great Inflation Era 1960.q1 to 1983.q4	Great Moderation Era 1984.q1 to 2007.q3	Great Recession Era 2007.q4 to 2019.q2
	A. Hybrid FIRE[1]: $\widetilde{E}_t\pi_{t+1} = \gamma_f\, E_t\pi_{t+1} + \left(1-\gamma_f\right)\pi_{t-1}$		
$\widehat{\kappa}$	-0.000	-0.002	0.073
	(0.025)	(0.019)	(0.082)
$\widehat{\gamma}_f$	0.809***	0.972***	0.823***
	(0.097)	(0.140)	(0.226)
$\widehat{\delta}$	-0.002	0.002	0.021
	(0.008)	(0.007)	(0.018)
$\widehat{\varphi}$	-0.002	-0.002	-0.004**
	(0.002)	(0.002)	(0.002)
	B. Accelerationist: $\widetilde{E}_t\pi_{t+1} = \left(\pi_{t-1}+\pi_{t-2}+\pi_{t-3}+\pi_{t-4}\right)/4$		
$\widehat{\kappa}$	0.130***	0.050**	0.070**
	(0.041)	(0.024)	(0.035)
$\widehat{\delta}$	-0.004	-0.005	0.011**
	(0.012)	(0.004)	(0.006)
$\widehat{\varphi}$	0.010***	0.000	-0.006***
	(0.001)	(0.002)	(0.001)
	C. Imperfect information: $\widetilde{E}_t\pi_{t+1} = \widetilde{E}_{t-1}\pi_t + \lambda(\pi_t - \widetilde{E}_{t-1}\pi_t)$		
$\widehat{\kappa}$	0.157***	0.061**	0.153**
	(0.040)	(0.027)	(0.085)
$\widehat{\lambda}$	0.162**	0.218**	0.079
	(0.077)	(0.112)	(0.087)
$\widehat{\delta}$	-0.014	-0.004	0.016**
	(0.014)	(0.005)	(0.009)
$\widehat{\varphi}$	0.016***	0.000	-0.006***
	(0.004)	(0.002)	(0.002)
Obs.	96	95	47

Notes: The asterisks ***, **, and * denote significance at the 1, 5, and 10 percent levels, respectively. The estimation uses quarterly inflation rates (not annualized). [1]Due to the lead term π_{t+1}, the hybrid FIRE model uses one less observation less of both y_t and π_t^{oil} in each subsample. Newey-West standard errors are shown in parentheses. Real GDP is detrended using a two-sided HP filter with $\lambda = 1600$.

Table E7: NKPC estimates using detrended GDP (2 of 2)

	Great Inflation Era 1960.q1 to 1983.q4	Great Moderation Era 1984.q1 to 2007.q3	Great Recession Era 2007.q4 to 2019.q2
		D. Survey data	
		1-q SPF	
$\widehat{\kappa}$		0.050**	0.072*
		(0.026)	(0.047)
$\widehat{\delta}$		−0.013**	0.011
		(0.006)	(0.009)
$\widehat{\varphi}$		−0.001	−0.007***
		(0.002)	(0.001)
$\widehat{c}$		0.000	0.000
		(0.000)	(0.000)
		5-y MSC[1]	
$\widehat{\kappa}$		0.041***	0.166***
		(0.016)	(0.067)
$\widehat{\delta}$		0.005	0.014**
		(0.005)	(0.007)
$\widehat{\varphi}$		−0.003**	−0.006***
		(0.002)	(0.002)
$\widehat{c}$		−0.003***	−0.003***
		(0.000)	(0.000)
		10-y SPF[2]	
$\widehat{\kappa}$		0.057***	0.151**
		(0.017)	(0.007)
$\widehat{\delta}$		0.006	0.020**
		(0.005)	(0.011)
$\widehat{\varphi}$		−0.007***	−0.007***
		(0.001)	(0.002)
$\widehat{c}$		−0.001***	−0.001***
		(0.000)	(0.000)
Obs.	96	95	47

Notes: The asterisks ***, **, and * denote significance at the 1, 5, and 10 percent levels, respectively. The estimation uses quarterly inflation rates (not annualized). [1]Great Moderation subsample starts in 1990.q3. [2]Great Moderation subsample starts in 1992.q1. Newey-West standard errors are shown in parentheses. Real GDP is detrended using a two-sided HP filter with $\lambda = 1600$.

E.5 Alternative inflation measure: Core PCE inflation

Table E8: NKPC estimates using core PCE inflation (1 of 2)

	Great Inflation Era 1961.q3 to 1983.q4	Great Moderation Era 1984.q1 to 2007.q3	Great Recession Era 2007.q4 to 2019.q2
	A. Hybrid FIRE[1]: $\widetilde{E}_t\pi_{t+1} = \gamma_f \, E_t\pi_{t+1} + \left(1-\gamma_f\right)\pi_{t-1}$		
$\widehat{\kappa}$	-0.026^{*}	-0.002	-0.002
	(0.017)	(0.006)	(0.006)
$\widehat{\gamma}_f$	1.004^{***}	0.994^{***}	0.984^{***}
	(0.259)	(0.221)	(0.226)
$\widehat{\delta}$	0.002	0.001	-0.004
	(0.007)	(0.003)	(0.006)
$\widehat{\varphi}$	-0.003	0.000	0.004^{*}
	(0.003)	(0.001)	(0.003)
	B. Accelerationist: $\widetilde{E}_t\pi_{t+1} = \left(\pi_{t-1}+\pi_{t-2}+\pi_{t-3}+\pi_{t-4}\right)/4$		
$\widehat{\kappa}$	0.044^{***}	0.014^{**}	0.008
	(0.010)	(0.007)	(0.009)
$\widehat{\delta}$	-0.005	-0.002	0.017^{*}
	(0.008)	(0.005)	(0.010)
$\widehat{\varphi}$	0.011^{***}	0.001	0.002
	(0.003)	(0.002)	(0.002)
	C. Imperfect information: $\widetilde{E}_t\pi_{t+1} = \widetilde{E}_{t-1}\pi_t + \lambda(\pi_t - \widetilde{E}_{t-1}\pi_t)$		
$\widehat{\kappa}$	0.018^{**}	0.019	0.024^{*}
	(0.009)	(0.024)	(0.017)
$\widehat{\lambda}$	0.538^{***}	0.243	0.071
	(0.180)	(0.233)	(0.066)
$\widehat{\delta}$	-0.007^{*}	-0.003	0.008^{*}
	(0.005)	(0.007)	(0.006)
$\widehat{\varphi}$	0.007^{**}	0.001	0.002^{*}
	(0.004)	(0.003)	(0.001)
Obs.	96	95	47

Notes: The asterisks ***, **, and * denote significance at the 1, 5, and 10% levels, respectively. The estimation uses quarterly inflation rates (not annualized). [1]Due to the lead term π_{t+1}, the hybrid FIRE model uses one less observation less of both y_t and π_t^{oil} in each subsample Newey-West standard errors are shown in parentheses. Due to limited data availability, the estimation for the Great Inflation Era starts in 1961.q3.

Table E9: NKPC estimates using core PCE inflation (2 of 2)

	Great Inflation Era 1960.q1 to 1983.q4	Great Moderation Era 1984.q1 to 2007.q3	Great Recession Era 2007.q4 to 2019.q2
		D. Survey data	
		1-q SPF	
$\widehat{\kappa}$		-0.019^{*}	-0.009
		(0.012)	(0.012)
$\widehat{\delta}$		0.000	0.013^{*}
		(0.005)	(0.008)
$\widehat{\varphi}$		-0.002^{**}	0.000
		(0.001)	(0.002)
$\widehat{c}$		-0.001^{***}	-0.001^{***}
		(0.000)	(0.000)
		5-y MSC[1]	
$\widehat{\kappa}$		0.008	0.042^{***}
		(0.009)	(0.011)
$\widehat{\delta}$		0.000	0.004
		(0.003)	(0.004)
$\widehat{\varphi}$		0.000	0.003^{***}
		(0.001)	(0.001)
$\widehat{c}$		-0.005^{***}	-0.003^{***}
		(0.000)	(0.000)
		10-y SPF[2]	
$\widehat{\kappa}$		0.015	0.026^{***}
		(0.016)	(0.008)
$\widehat{\delta}$		0.011	0.005^{*}
		(0.006)	(0.003)
$\widehat{\varphi}$		0.000	0.002^{***}
		(0.003)	(0.000)
$\widehat{c}$		-0.002	-0.002^{***}
		(0.000)	(0.000)
Obs.	96	95	47

Notes: The asterisks ***, **, and * denote significance at the 1, 5, and 10% levels, respectively. The estimation uses quarterly inflation rates (not annualized). Newey-West standard errors are shown in parentheses. [1]Great Moderation subsample starts in 1990.q3. [2]Great Moderation subsample starts in 1990.q3. Due to limited data availability, the estimation for the Great Inflation Era starts in 1961.q3.

E.6 Alternative instruments set

Tables E10 and E11 show the estimation results when we replace our baseline instruments set from Section 3 with a larger set of instruments, consisting of four lags of core CPI inflation, two lags of wage inflation, the CBO output gap, and oil price inflation. For the specifications using survey data, we add one lag of survey expectations to the set of instruments. As shown, the use of a larger set of instruments does not change any of our basic results.

Table E10: NKPC estimates using alternative instruments (1 of 2)

	Great Inflation Era 1960.q1 to 1983.q4	Great Moderation Era 1984.q1 to 2007.q3	Great Recession Era 2007.q4 to 2019.q2
	A. Hybrid FIRE[1]: $\widetilde{E}_t\pi_{t+1} = \gamma_f\, E_t\pi_{t+1} + \left(1-\gamma_f\right)\pi_{t-1}$		
$\widehat{\kappa}$	-0.071^{***}	-0.003	0.009^{*}
	(0.020)	(0.012)	(0.006)
$\widehat{\gamma}_f$	1.235^{***}	0.694^{***}	0.789^{***}
	(0.148)	(0.113)	(0.122)
$\widehat{\delta}$	0.037^{**}	-0.015^{***}	0.013^{***}
	(0.021)	(0.006)	(0.005)
$\widehat{\varphi}$	-0.016^{***}	0.000	-0.003^{***}
	(0.006)	(0.002)	(0.001)
	B. Accelerationist: $\widetilde{E}_t\pi_{t+1} = \left(\pi_{t-1}+\pi_{t-2}+\pi_{t-3}+\pi_{t-4}\right)/4$		
$\widehat{\kappa}$	0.080^{***}	0.036^{***}	0.022^{***}
	(0.018)	(0.010)	(0.008)
$\widehat{\delta}$	-0.021^{*}	-0.015^{***}	0.011^{***}
	(0.015)	(0.005)	(0.003)
$\widehat{\varphi}$	0.017^{***}	0.004^{**}	-0.003^{***}
	(0.004)	(0.002)	(0.001)
	C. Imperfect information: $\widetilde{E}_t\pi_{t+1} = \widetilde{E}_{t-1}\pi_t + \lambda(\pi_t - \widetilde{E}_{t-1}\pi_t)$		
$\widehat{\kappa}$	0.075^{***}	0.036^{**}	0.061^{***}
	(0.014)	(0.017)	(0.009)
$\widehat{\lambda}$	0.232^{***}	0.101^{**}	0.000
	(0.058)	(0.052)	(0.006)
$\widehat{\delta}$	-0.022^{*}	-0.020^{***}	0.012^{***}
	(0.014)	(0.006)	(0.003)
$\widehat{\varphi}$	0.009^{***}	0.006^{***}	-0.003^{**}
	(0.001)	(0.002)	(0.001)
Obs.	96	95	47

Notes: The asterisks ***, **, and * denote significance at the 1, 5, and 10% levels, respectively. The estimation uses quarterly inflation rates (not annualized). [1]Due to the lead term π_{t+1}, the hybrid FIRE model uses one less observation of both y_t and π_t^{oil} in each subsample. Newey-West standard errors are shown in parentheses.

Table E11: NKPC estimates using alternative instruments (2 of 2)

	Great Inflation Era 1960.q1 to 1983.q4	Great Moderation Era 1984.q1 to 2007.q3	Great Recession Era 2007.q4 to 2019.q2
		D. Survey data	
		1-q SPF	
$\widehat{\kappa}$		0.001	0.021**
		(0.023)	(0.010)
$\widehat{\delta}$		−0.021***	0.003*
		(0.004)	(0.002)
$\widehat{\varphi}$		0.000	−0.004***
		(0.002)	(0.001)
$\widehat{c}$		0.000	0.000**
		(0.000)	(0.000)
		5-y MSC[1]	
$\widehat{\kappa}$		0.014	0.048***
		(0.016)	(0.011)
$\widehat{\delta}$		−0.015***	0.008***
		(0.004)	(0.003)
$\widehat{\varphi}$		0.006***	−0.005***
		(0.002)	(0.000)
$\widehat{c}$		−0.003***	−0.002***
		(0.000)	(0.000)
		10-y SPF[2]	
$\widehat{\kappa}$		0.049***	0.059***
		(0.012)	(0.010)
$\widehat{\delta}$		0.000	0.012***
		(0.003)	(0.003)
$\widehat{\varphi}$		−0.008***	−0.004***
		(0.002)	(0.001)
$\widehat{c}$		0.000	0.000
		(0.000)	(0.000)
Obs.	96	95	47

Notes: The asterisks ***, **, and * denote significance at the 1, 5, and 10% levels, respectively. The estimation uses quarterly inflation rates (not annualized). Newey-West standard errors are shown in parentheses. [1]Great Moderation subsample starts in 1990.q3. [2]Great Moderation subsample starts in 1992.q1.

F Appendix: Imperfect information model

The New Keynesian model is given by the following three equations:

$$\pi_t = \beta \widetilde{E}_t \pi_{t+1} + \kappa y_t + u_t, \tag{F.1}$$

$$y_t = -\kappa \mu_\pi \left(\pi_t - \pi_t^*\right) + v_t, \tag{F.2}$$

$$\pi_t^* = \rho \pi_{t-1}^* + \varepsilon_t. \tag{F.3}$$

F.1 Imperfect information: Signal extraction problem

We first solve for the rational one-period ahead inflation forecast $\widetilde{E}_t \pi_{t+1}$ as follows. Substituting equation (F.2) into equation (F.1) to eliminate the unobservable y_t and then solving for π_t yields:

$$\pi_t = \frac{1}{1+\kappa^2 \mu_\pi} \left[\beta \widetilde{E}_t \pi_{t+1} + \kappa^2 \mu_\pi \pi_t^* + \kappa v_t + u_t\right], \tag{F.4}$$

where π_t^* is not observed by the agent. Iterating the above expression ahead one period and then taking the time t expectation yields

$$\widetilde{E}_t \pi_{t+1} = \frac{1}{1+\kappa^2 \mu_\pi} \left[\beta \widetilde{E}_t \pi_{t+2} + \kappa^2 \mu_\pi \widetilde{E}_t \pi_{t+1}^*\right]. \tag{F.5}$$

From equation (F.3), we have $\widetilde{E}_t \pi_{t+1}^* = \rho \widetilde{E}_t \pi_t^*$ which can be substituted into equation (F.5) to yield

$$\widetilde{E}_t \pi_{t+1} = \frac{1}{1+\kappa^2 \mu_\pi} \left[\beta \widetilde{E}_t \pi_{t+2} + \kappa^2 \mu_\pi \rho \widetilde{E}_t \pi_t^*\right]. \tag{F.6}$$

Iterating equation (F.6) ahead one period and then taking the time t expectation yields an expression for $\widetilde{E}_t \pi_{t+2}$ which is then substituted into the right-hand side of equation (F.6). Proceeding in the manner with repeated forward substitution yields:

$$\widetilde{E}_t \pi_{t+1} = \frac{\kappa^2 \mu_\pi \rho}{1+\kappa^2 \mu_\pi - \beta \rho} \widetilde{E}_t \pi_t^*. \tag{F.7}$$

Next we compute the agent's optimal estimate of π_t^*. The agent can only observe π_t and $\widetilde{E}_t \pi_{t+1}$. Substituting y_t from equation (F.2) into equation (F.1) and solving for π_t^* on the left-hand side yields:

$$\pi_t^* = \underbrace{\frac{1}{\kappa^2 \mu_\pi}\left[\left(1+\kappa^2 \mu_\pi\right) \pi_t - \beta \widetilde{E}_t \pi_{t+1}\right]}_{\text{signal}} - \underbrace{\frac{1}{\kappa^2 \mu_\pi}\left(\kappa v_t + u_t\right)}_{\text{noise}}, \tag{F.8}$$

where the first term on the right-hand side is the agent's signal for π_t^* and the second term is the noise component. The agent's optimal estimate of the inflation target π_t^* is then given by:

$$\widetilde{E}_t\pi_t^* = \lambda_\pi \left\{ \frac{1}{\kappa^2\mu_\pi} \left[\left(1+\kappa^2\mu_\pi\right)\pi_t - \beta\widetilde{E}_t\pi_{t+1} \right] \right\} + \left(1-\lambda_\pi\right)\widetilde{E}_{t-1}\pi_t^*, \tag{F.9}$$

where the steady state Kalman gain λ_π is given by equation (19) in the main text. The signal-to-noise ratio is given by

$$\phi \equiv \frac{\sigma_\varepsilon^2}{\left(\kappa^2\sigma_v^2 + \sigma_u^2\right) / \left(\kappa^2\mu_\pi\right)^2}. \tag{F.10}$$

Inserting the expression for $\widetilde{E}_t\pi_{t+1}$ from equation (F.7) into equation (F.9) and then solving for $\widetilde{E}_t\pi_t^*$ yields:

$$\widetilde{E}_t\pi_t^* = \frac{1+\kappa^2\mu_\pi - \beta\rho}{1+\kappa^2\mu_\pi - \beta\rho\left(1-\lambda_\pi\right)} \left[\frac{\lambda_\pi\left(1+\kappa^2\mu_\pi\right)}{\kappa^2\mu_\pi}\pi_t + \left(1-\lambda_\pi\right)\widetilde{E}_{t-1}\pi_t^* \right], \tag{F.11}$$

which corresponds to equation (18) in the main text. When $\beta \simeq 1$ and $\rho \simeq 1$, the above expression maps directly to the inflation forecast rule (6) that we employ in the NKPC estimation exercise. In this case, the forecast rule gain parameter λ is given by

$$\lambda \equiv \frac{\lambda_\pi\left(1+\kappa^2\mu_\pi\right)}{\lambda_\pi + \kappa^2\mu_\pi}. \tag{F.12}$$