How Much Has the Fed's New Policy Framework Contributed to Inflation?

Dario Cardamone
Notre Dame

Victoria Consolvo
Notre Dame

Irakli Shalikashvili
Notre Dame

Eric Sims
Notre Dame and NBER

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Abstract

We evaluate the impact of the Federal Reserve's August 2020 change in policy framework on inflation. Using a representative agent New Keynesian model, we simulate inflationary shocks to the economy and compare the path of inflation under a standard Taylor rule (STR) to that under asymmetric output growth responses (AR) and average inflation targeting (AIT). We find that from 2020-Q3 to 2021-Q2, a policy rule with both AR and AIT generates higher inflation than the STR. After 2021, a rule with AIT alone generates lower inflation than either the STR or a rule containing both AIT and AR.

Keywords: monetary policy, make-up strategies, inflation targeting, DSGE
JEL Codes: E31, E52, E58

1 Introduction

Driven by a steady increase in inflation since December 2020, researchers have spent the last two years asking and answering the same question: why is inflation high right now? A large literature has emerged proposing different contributing factors to this historic run-up, with drivers ranging from supply-chain bottlenecks to discretionary fiscal stimulus, among many others.[1] Yet just one quarter prior to the beginning of the surge, two-percent inflation had remained an elusive goal for the Fed. Reeling from the COVID-19 pandemic's effects on the economy, and partly to address perpetual undershooting of its inflation target in a low-interest-rate world, the Fed announced a change to its policy framework in August 2020. Features of the new framework include a shift to focusing on shortfalls from maximum employment rather than deviations, and to focusing on average inflation "over some period of time" rather than inflation each period, while still targeting 2 percent inflation[2]. While these "makeup strategies" were not new concepts to the Fed or to the public at the time they were implemented (see Nessén and Vestin (2005) for an earlier discussion of AIT and related strategies), the 2020 statement marks the first time the Federal Reserve had publicly announced its intention of utilizing such strategies.

The 12-month growth rate in headline (Personal Consumption Expenditure) PCE peaked at 7 percent in June 2022, having more than quintupled since August 2020. In this paper we will investigate how much of the inflation we observed over this period can be attributed to the Fed's new policy rule. Was the burst in inflation caused by a sequence of shocks, or a change in the policy framework? We view this question through the lens of a general equilibrium model. Using a representative agent New Keynesian (RANK) model, we simulate inflationary shocks to the economy and compare the path of inflation under a standard Taylor rule (STR) to that under a rule with asymmetric output growth responses (AR) and average inflation targeting (AIT). More specifically, we compare rules with AIT and AR together, AIT individually, and a rule with the STR with AR, to the pre-2020-Q3 policy of the STR. We find that from 2020-Q3 to 2021-Q2, a policy rule with both AR and AIT generates higher inflation than the STR. After 2021, a rule with AIT alone generates lower inflation than either a standard Taylor rule or a rule containing both AIT and AR.

[1] Reis (2022) provides a survey of multiple hypotheses, but argues that in each case the real culprit was increased tolerance for inflation above target by central banks.

[2] The Statement on Longer-Run Goals and Monetary Policy Strategy is available on the Board website at https://www.federalreserve.gov/monetarypolicy/files/FOMC_LongerRunGoals.pdf, where it has been reaffirmed each year since its last revision in 2020.

A potential concern with these exercises is that the Fed did not actually operate according to its stated policies. A series of interest-rate hikes throughout 2022 were accompanied by FOMC statements indicating that it was "strongly committed" to returning inflation to the long-standing symmetric target of 2-percent.[3] In a speech at the Jackson Hole Symposium in 2020, Jerome Powell stated that "if excessive inflationary pressures were to build or inflation expectations were to ratchet above levels consistent with our goal, we would not hesitate to act." This language is not indicative of a makeup-strategy, but rather something resembling "asymmetric AIT." In other words, The Fed will conduct monetary policy in line with AIT when inflation is below 2-percent, but will return to pre-2020 inflation targeting once it goes above 2-percent. Our exercise, however, amounts to taking the Fed at its word. After unanimous agreement on its new goals in 2020 we assume that the FOMC adopted the proposed framework that it communicated to the public. Conditional on this assumption, we perform our analysis.

A key piece from the AIT policy, the length of the window over which inflation will be averaged, was excluded from the August 2020 statement. In this paper we will use a 4 quarter window for our analysis, and assume that the central bank in our model uses its monetary policy strategy consistently over time. In other words, we do not allow for the central bank to use "flexible" AIT. Jia and Wu (2022) examines the impact of a central bank remaining intentionally ambiguous about a fixed horizon for AIT. They find that the optimal horizon of AIT is time-dependent, and that if the central bank has full credibility that this time-inconsistent strategy is welfare-improving.

Part of the question we address in this paper is whether the actions the Fed took in reality led to an undue increase in inflation, which involves asking whether the Fed neglected to raise interest rates soon enough to subdue inflationary pressures. One story could be that the Fed instead intended to use its balance sheet policy as a form of forward guidance to signal future rate hikes. In March 2020, the Fed began to take unprecedented action regarding its balance sheet. Bond-buying to provide liquidity to financial markets during the early stages of the COVID-19 pandemic and throughout the subsequent recession was accompanied by an indefinite commitment to remain at the zero lower bound (ZLB). The Fed began to slow its pace of these large-scale asset purchases (LSAPs), a process known as "tapering," as the economy

[3]See, for example, the post-FOMC meeting statement in June 2022 following its largest rate hike in almost two decades.

began recovering toward the later part of 2021. However, in his November 2021 press conference Fed Chairman Powell stated “Our decision today to begin tapering our asset purchases does not imply any direct signal regarding our interest rate policy,” and that more restrictive conditions for economic conditions had to be met before utilizing short-term interest rate policy. While the Fed might not have intended for tapering to signal future rate increases it’s new policy framework was coincident with tapering over this period. As such, we use the Wu-Xia shadow rate (Wu and Xia, 2016) to control for this and other forms of forward guidance that were at play during the ZLB period.

Our paper is not the first to quantify the effect of the new policy framework on the economy. There are numerous papers that have analyzed the effects of one component of the new framework in the absence of the other. Amano et al. (2020) uses a two-agent New Keynesian model where a fraction of firms have adaptive expectations to compare inflation and output volatility under AIT, price-level targeting (PLT), and standard inflation-targeting. However, their analysis does not also consider asymmetric unemployment targeting, whereas our model includes it directly into several of the policy-rule specifications.

Bundick and Petrosky-Nadeau (2021) uses a model featuring frictional labor markets, nominal rigidities, and the ZLB to compare the effects of the “shortfalls” policy to those of the symmetric deviations policy. We do not incorporate the ZLB explicitly in favor of using the Wu-Xia shadow rate to capture the other unconventional monetary policies happening concurrently. Similarly, Bundick and Petrosky-Nadeau (2021) focuses exclusively on the asymmetric employment rule.

Much of the Fed’s internal background research evaluating the potential impacts of its new policy framework is now public. Arias et al. (2020) compares the stabilization performance of different specifications of inflation-targeting rules using three different models in both a mild-recession scenario with low inflation and a mild recession scenario with a positive inflation gap. However, it only alludes to but does not analyze directly how these policies might exacerbate a highly-inflationary environment. To the extent that we believe that shifting to the joint use of AIT and AR was potentially a contributing factor to the continual rise in inflation rather than the root cause, we find it essential to understand these policies in the context of a series of inflationary shocks.

The remainder of the paper proceeds as follows. Section 2 provides details of our model and descriptions of the alternative interest rate rules. We then present the quantitative results of our model in Section 3, including simulated paths of inflation under each monetary policy regime. Section 4 concludes.

2 Model

To perform our counterfactual exercises, we extend the model in Cúrdia et al. (2015) to incorporate the different policy regimes. In what follows, we provide a description of the behavior of households, firms, and monetary policy.

2.1 Households

Households choose consumption C_t and supply their specialized labor input h_t for the production of a specific final good. As a consequence of labor market segmentation, the wage w_t differs across households. However, the household can fully insure against idiosyncratic wage risk by buying at time-t state-contingent securities D_{t+1} at price $Q_{t,t+1}$. Besides labor income, households earn profits Γ_t from ownership of the firms. The flow budget constraint for the household is

$$P_t C_t + \mathbb{E}_t \left(Q_{t,t+1} D_{t+1} \right) = w_t h_t + D_t + \Gamma_t \tag{1}$$

where $P_t = \left(\int_0^1 P_t \left(i\right)^{1-\varepsilon_t} di \right)^{1/(1-\varepsilon_t)}$ is the aggregate price index and $p_t\left(i\right)$ is the dollar price of the i^{th} good variety.

The household's maximization problem is thus

$$\max_{C_t, h_t, D_{t+1}} \mathbb{E}_0 \left\{ \sum_{t=0}^{\infty} \beta^t \prod_{s=0}^{t} e^{-\delta_t} \left[\ln \left(C_t - \eta C_{t-1} \right) - \frac{\left(h_t\right)^{1+\omega}}{1+\omega} \right] \right\}$$

$$\text{subject to } P_t C_t + \mathbb{E}_t \left(Q_{t,t+1} D_{t+1} \right) = w_t h_t + D_t + \Gamma_t,$$

where δ_t is an aggregate preference shock that shifts the intertemporal allocation of consumption without affecting the intratemporal margin between labor and leisure, and follows a stationary AR$\left(1\right)$ process

$$\delta_t = \rho_\delta \delta_{t-1} + \varepsilon_t^\delta.$$

The corresponding first order conditions are:

$$\Lambda_t = \frac{1}{C_t - \eta C_{t-1}} - \eta\beta\mathbb{E}_t\left\{\frac{e^{-\delta_{t+1}}}{C_{t+1} - \eta C_t}\right\} \tag{2}$$

$$(h_t)^\omega = \Lambda_t \frac{w_t}{P_t} \tag{3}$$

$$\Lambda_t = \beta R_t \mathbb{E}_t\left\{e^{-\delta_{t+1}}\frac{\Lambda_{t+1}}{\Pi_{t+1}}\right\} \tag{4}$$

where $\Pi_{t+1} = \frac{P_{t+1}}{P_t}$ and the gross nominal interest rate is $R_t = \frac{1}{\mathbb{E}_t\{Q_{t,t+1}\}}$. Equation (2) gives the marginal effect on utility of an increase in current consumption, Equation (3) is the intratemporal labor supply condition, and Equation (4) is the Euler equation for bonds.

2.2 Firms

There is a continuum of monopolistically competitive firms, each producing a differentiated intermediate good, and a perfectly competitive firm that combines intermediate goods into a single final good.

2.2.1 Final Goods Firms

The final good producer packs intermediate goods, $Y_t(i)$, using the following CES aggregator:

$$Y_t = \left(\int_0^1 Y_t(i)^{\frac{\varepsilon_t - 1}{\varepsilon_t}} di\right)^{\frac{\varepsilon_t}{\varepsilon_t - 1}} \tag{5}$$

where ε_t measures the time-varying elasticity of demand for each intermediate good; hence, it acts as a markup, or cost-push shock. Here, the cost-push shock follows an autoregressive process:

$$\ln(\varepsilon_t) = (1 - \rho_u)\ln\varepsilon + \rho_u \ln(\varepsilon_{t-1}) + \epsilon_t^u$$

with $\varepsilon > 1$ and $1 > \rho_u \geq 0$, where the zero-mean, serially-uncorrelated innovation ϵ_t^u is normally distributed with standard deviation σ_u. The firm's profit maximization problem yields the following demand schedule for intermediate varieties:

$$Y_t(i) = \left(\frac{P_t(i)}{P_t}\right)^{-\varepsilon_t} Y_t \tag{6}$$

Equation (6) is a function of the price of intermediate good i, $P_t(i)$, aggregate price index, P_t, and aggregate output, Y_t. Ultimately, the aggregate price level is expressed as follows

$$P_t = \left(\int_0^1 P_t(i)^{1-\varepsilon_t} di \right)^{\frac{1}{1-\varepsilon_t}}. \tag{7}$$

2.2.2 Intermediate Goods Producers

A generic intermediate good producer i uses labor, $h_t(i)$, as the only input to the production function:

$$Y_t(i) = A_t h_t(i) \tag{8}$$

where A_t represents an exogenous level of technological progress and is assumed to be the same across all firms, and where $MC_t(i)$ is the real marginal cost faced by firm i. They are subject to nominal rigidities as in Calvo (1983), where each firm can reset its price with probability $1-\theta$ each period independently of the time elapsed since the last price reset. Indexation to lagged inflation means that an unchanged price in period $t+s$ will be

$$P_{t+s}(i) = P_t(i) \left(\frac{P_{t+s-1}}{P_{t-1}} \right)^{\gamma}. \tag{9}$$

A generic firm i that can reset its price selects the optimal price level, $P_t^*(i)$, to maximize the following objective function

$$\max_{p_t(i), h_t(i)} \mathbb{E}_t \left\{ \sum_{s=0}^{\infty} (\theta\beta)^s \Lambda_{t+s} \left(P_{t+s}(i) Y_{t+s}(i) - w_{t+s}(i) h_{t+s}(i) \right) \right\} \tag{10}$$

subject to the demand schedule in (6) and production technology (8), where $\Gamma_t(i) = P_{t+s}(i) Y_{t+s}(i) - w_{t+s}(i) h_{t+s}(i)$.

After substituting in the demand schedule from Equation (6) and indexation equation from (9), writing the objective function in real terms, taking the first order condition with respect to $P_t(i)$ will yield

$$P_t^*(i) = \mathcal{M}_t \frac{\mathbb{E}_t \left\{ \sum_{s=0}^{\infty} (\theta\beta)^s \Lambda_{t+s} MC_{t+s} \left(\frac{P_{t+s-1}}{P_{t-1}} \right)^{-\varepsilon_t \gamma} P_{t+s}^{\varepsilon_t} Y_{t+s} \right\}}{\mathbb{E}_t \left\{ \sum_{s=0}^{\infty} (\theta\beta)^s \Lambda_{t+s} \left(\frac{P_{t+s-1}}{P_{t-1}} \right)^{(1-\varepsilon_t)\gamma} P_{t+s}^{\varepsilon_t - 1} Y_{t+s} \right\}} \tag{11}$$

where $MC_{t+s} \equiv \frac{\Psi_{t+s}}{P_{t+s}}$ is the real marginal cost common to all firms and $\mathcal{M}_t = \frac{\varepsilon_t}{\varepsilon_t - 1}$ is the price markup. Taking first order condition with respect to $h_t(i)$ will yield

$$MC_t = \frac{w_t\left(i\right)/P_t}{A_t}. \tag{12}$$

Denote $\mathbb{E}_t\left\{\sum_{s=0}^{\infty}\left(\theta\beta\right)^s\Lambda_{t+s}MC_{t+s}\left(\frac{P_{t+s-1}}{P_{t-1}}\right)^{-\varepsilon_t\gamma}P_{t+s}^{\varepsilon_t}Y_{t+s}\right\}$ by $X_{1,t}$. Thus we will have

$$X_{1,t} = \Lambda_t MC_t P_t^{\varepsilon_t} Y_t + \theta\beta\Pi_t^{-\varepsilon_t\gamma}\mathbb{E}_t\left[X_{1,t+1}\right]$$

and if we define $x_{1,t} = X_{1,t}/P_t^{\varepsilon_t}$, then

$$x_{1,t} = \Lambda_t MC_t Y_t + \theta\beta\mathbb{E}_t\left[\left(\frac{\Pi_{t+1}}{\Pi_t^{\gamma}}\right)^{\varepsilon_t}x_{1,t+1}\right]. \tag{13}$$

By similar logic, we will have

$$x_{2,t} = \Lambda_t Y_t + \theta\beta\mathbb{E}_t\left[\left(\frac{\Pi_{t+1}}{\Pi_t^{\gamma}}\right)^{\varepsilon_t-1}x_{2,t+1}\right]. \tag{14}$$

Define $\Pi_t^* = \frac{P_t^*}{P_t}$. The price setting equation then becomes

$$\Pi_t^* = \mathcal{M}_t\frac{x_{1,t}}{x_{2,t}}. \tag{15}$$

Dividing Equation (7) by $P_t^{1-\epsilon}$ yields

$$1 = \left(1-\theta\right)\left(\Pi_t^*\right)^{1-\epsilon} + \theta\Pi_t^{\epsilon-1}. \tag{16}$$

2.3 Monetary Policy

The following set of monetary policy rules describe each of the alternative scenarios we will consider. We describe each case in turn.

We note here that another omitted component of the Fed's new strategy is the definition of "maximum employment" from which shortfalls would be measured. By the end of 2020, the economy was already considered to be running hot. But running hot relative to what? In our benchmark specifications, we use output growth, denoted by $\ln\left(\frac{Y_t}{Y_{t-1}}\right)$, rather than the deviation of output from its steady state value, in the policy rule. Output growth can be a more flexible indicator of economic conditions, as it reflects changes in the economy over time, rather than just the current state. This can be useful in situations where policymakers need to adjust their monetary policy response to changing economic conditions. This can be important when policymakers want to respond to changes in economic conditions that are cyclical in nature. We express the nominal interest rate and inflation as log-deviations from their steady states:

1. **STR:**
$$\ln \frac{R_t}{R} = \rho \ln \frac{R_{t-1}}{R} + (1-\rho)\left(\phi_\pi \ln \frac{\Pi_t}{\Pi} + \phi_x \ln \frac{Y_t}{Y_{t-1}}\right) + \varepsilon_t^r$$

2. **AIT:**
$$\ln \frac{R_t}{R} = \rho \ln \frac{R_{t-1}}{R} + (1-\rho)\left(\frac{\phi_\pi}{4}\left(\sum_{i=t-3}^{t} \ln \frac{\Pi_i}{\Pi}\right) + \phi_x \ln \frac{Y_t}{Y_{t-1}}\right) + \varepsilon_t^r$$

3. **AR**:
$$\begin{cases} \ln \frac{R_t}{R} = \rho \ln \frac{R_{t-1}}{R} + (1-\rho)\left(\phi_\pi \ln \frac{\Pi_t}{\Pi} + \phi_x \ln \frac{Y_t}{Y_{t-1}}\right) + \varepsilon_t^r & \text{if } \frac{Y_t}{Y_{t-1}} < 1 \\ \ln \frac{R_t}{R} = \rho \ln \frac{R_{t-1}}{R} + (1-\rho)\,\phi_\pi \ln \frac{\Pi_t}{\Pi} + \varepsilon_t^r & \text{if } \frac{Y_t}{Y_{t-1}} \geq 1 \end{cases}$$

4. **AIT and ATR**:
$$\begin{cases} \ln \frac{R_t}{R} = \rho \ln \frac{R_{t-1}}{R} + (1-\rho)\left(\frac{\phi_\pi}{4}\left(\sum_{i=t-3}^{t} \ln \frac{\Pi_i}{\Pi}\right) + \phi_x \ln \frac{Y_t}{Y_{t-1}}\right) + \varepsilon_t^r & \text{if } \frac{Y_t}{Y_{t-1}} < 1 \\ \ln \frac{R_t}{R} = \rho \ln \frac{R_{t-1}}{R} + (1-\rho)\,\frac{\phi_\pi}{4}\left(\sum_{i=t-3}^{t} \ln \frac{\Pi_i}{\Pi}\right) + \varepsilon_t^r & \text{if } \frac{Y_t}{Y_{t-1}} \geq 1 \end{cases}$$

Case 1 is just the standard Taylor rule, which contains an inertial term and includes both inflation and output growth as factors to which the monetary authority will respond. Case 2, AIT, is a rule that includes output growth as well as a measure of average inflation over a 4-period window. Case 3 includes both AIT and AR in the policy rule, such that the monetary authority will respond to average inflation over the specified window while responding to output growth only when output growth is negative. Case 4 is an asymmetric output growth response (AR) rule, meaning that central bank responds to output growth only when the growth is negative.

3 Quantitative Analysis

To solve the model, we use Dynare. To handle the occasionally-binding monetary policy rules where relevant, we use the occbin package available from Guerrieri and Iacoviello (2015), which implements piecewise linear perturbation. We estimate the model using data for output growth, inflation, and the nominal interest rate from 2020-Q1 to 2022-Q2.[4] We use the resulting smoothed shocks from Dynare to simulate the economy from 2020-Q1 onward.[5] All parameters are chosen in line with standard values in the literature and are listed in Table 1.

Parameter	Value or Target	Description
β	0.99	Discount factor
η	0.6	Internal habit formation
ω	1	Inverse Frisch elasticity
ρ_δ	0.7	AR coefficient: preference
θ	0.7	Price rigidity
γ	0.6	Price indexation parameter
ρ_δ	0.8	Preference AR(1) process coefficient
ρ_u	0.7	Cost-push AR(1) process coefficient
ϵ	10	Elasticity of substitution: goods
Π	1	Steady state (gross) inflation
ϕ_π	1.5	Taylor rule inflation coefficient
ϕ_y	0.5	Taylor rule output growth coefficient
ρ	0.7	Taylor rule inertial coefficient
π^*	1	Inflation target

Table 1. Calibrated Parameter Values

In Figure 1, we show the simulated paths of inflation in response to a sequence of cost-push, preference, and monetary policy shocks that hit the economy simultaneously in each period. Starting from 2020-Q3 when the new policy framework is adopted, we simulate the path of inflation under each alternative scenario. We assume that the response of the economy under a rule with AIT and AR combination reflects the reality. More precisely, we assume that monetary policy follows this mixture, while the others are counterfactual policies.

[4] For training data we use 2017-Q3 to 2019-Q4. Appendix A.1 contains a detailed description of the data.

[5] The occbin solver provides the smoothed shocks as part of its default output. We also performed this exercise without using the built-in command and obtain the same results.

We find that an AR approach, or where the monetary authority is responding just to shortfalls in output growth, results in consistently higher inflation than the alternatives. From 2020-Q3 to roughly 2021-Q2, the STR results in the lowest simulated inflation. However, a rule that responds only to average inflation targeting (AIT) yields only slightly higher inflation over the same period than the STR. Starting from 2021-Q2 AIT policy rule generates the lowest inflation compared to all other alternatives.

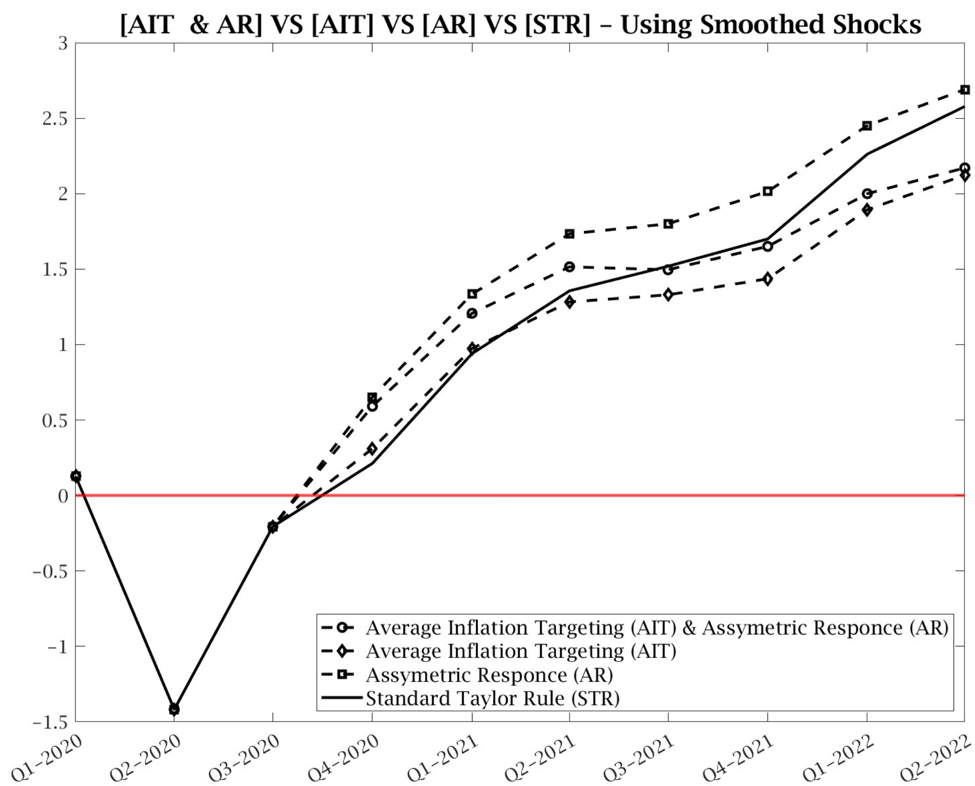

Figure 1. Simulated paths of inflation.

In the short-run, the standard Taylor rule yields the lowest inflation. But in the medium run, a rule with AIT performs best. This result provides intuition similar to that of discretion versus commitment. AIT can be thought of as target-based forward guidance: if inflation is low today, then AIT commits the central bank to low interest rates in the future.

3.1 Welfare Analysis

To evaluate the performance of the different policy regimes from 2020-Q3 onward, we derive a welfare loss function where period-t loss is given by[6]

$$\mathcal{L}_t \approx -\frac{1}{2}\left[\left(\chi_1\left(\beta\hat{y}_t - \hat{y}_{t-1}\right) + \chi_2\Delta\hat{y}_t^2\right)\left(1+\hat{z}_t\right) + \chi_3\pi_t^2 + \chi_4\hat{y}_t^2\right]. \tag{17}$$

We compute the welfare loss using the simulated data from the model for each quarter and include these estimates in Table 2.

Year	Quarter	AIT	AIT & AR	AR	STR
2020	3	-6.10	-6.92	-6.91	-5.72
2020	4	-0.02	-0.06	-0.08	-0.01
2021	1	-0.22	-0.32	-0.38	-0.21
2021	2	-0.38	-0.51	-0.65	-0.41
2021	3	-0.38	-0.48	-0.67	-0.48
2021	4	-0.54	-0.69	-0.94	-0.71
2022	1	-0.78	-0.87	-1.25	-1.07
2022	2	-0.95	-1.00	-1.48	-1.36

Table 2. Welfare Analysis

Starting in 2020-Q3 until 2021-Q1, a standard Taylor rule results in the least amount of welfare loss of the four rules. From 2021-Q2 onward, an AIT rule outperforms the others.

4 Conclusion

In August of 2020, the Fed revised its "Statement on Longer-Run Goals and Monetary Policy Strategy." In this paper, we use a quantitative general equilibrium model to assess whether this switch in the Fed's policy goals contributed to the inflation we are currently observing. Our study analyzed the impact of different monetary policy rules on inflation in response to various shocks. We found that an approach that only responds to shortfalls in output growth results in consistently higher inflation than the alternatives. The standard Taylor rule yields the lowest inflation in the short run, but in the medium run, a rule with average inflation targeting (AIT) performs best. This result is similar to the discretion versus commitment trade-off, where AIT

[6] Loss function is derived in Appendix A.2.

can be thought of as target-based forward guidance. Furthermore, we found that starting from 2021-Q2, an AIT rule generates the lowest inflation compared to all other alternatives. Our results suggest that the Federal Reserve's current policy of using a mixture of AIT and AR may not be optimal, and a rule with AIT alone may lead to better inflation outcomes.

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A Appendix

A.1 Data Description

Label	Frequency	Description	Source
GDP	Q	Gross domestic product	BEA (Table 1.1.5)
RGDP	Q	Real gross domestic product	BEA (Table 1.1.6)
P16	Q	Civilian non-institutional population, over 16	BLS (LNU00000000Q)
FFR	Q	Federal funds effective rate	St. Louis FRED
Label	**Description**		**Construction**
GDPDEF	GDP deflator		RGDP/GDP
y_t	Real per-capita output		ln(RGDP/P16)
Δy	Real per-capita output growth		Δ ln (RGDP/P16)
π_t	Inflation rate		Δ ln(GDPDEF)
i_t	Interest rate		$100 * \ln(1+\text{FFR}/400)$

Notes: The Federal funds rate is the quarterly average of the daily series. Series are demeaned before entering the model.

A.2 Loss Function

Define for convenience $X_t \equiv C_t - \eta C_{t-1}$. I will use the following result for second-order approximations of relative deviations in log deviations: $\frac{X_t - X}{X} \approx \hat{x}_t + \frac{1}{2}\hat{x}_t^2$, where $\hat{x}_t \equiv x_t - x \equiv \log(X_t/X)$. The utility flow is:

$$Z_t \left(\left[\ln(X_t) - \frac{h_t^{1+\omega}}{1+\omega} \right] \right)$$

where $Z_t \equiv \Pi_{s=0}^{t} e^{-\delta_s}$.

The second-order Taylor expansion of U_t around a steady state (X, h) yields

$$\begin{aligned} U_t - U \approx\ & U_x X \left(\tfrac{X_t - X}{X}\right) + U_h h \left(\tfrac{h_t - h}{h}\right) + \tfrac{1}{2} U_{xx} X^2 \left(\tfrac{X_t - X}{X}\right)^2 \\ & + \tfrac{1}{2} U_{hh} h^2 \left(\tfrac{h_t - h}{h}\right)^2 + U_x X \left(\tfrac{X_t - X}{X}\right)\left(\tfrac{Z_t - Z}{Z}\right) + U_h h \left(\tfrac{h_t - h}{h}\right)\left(\tfrac{Z_t - Z}{Z}\right) + t.i.p. \end{aligned} \quad (18)$$

In terms of log deviations, and ignoring terms of order higher than two, we get

$$U_t - U \approx U_x X \left(\hat{x}_t + \tfrac{1}{2}\hat{x}_t^2\right) + U_h h \left(\hat{h}_t + \tfrac{1}{2}\hat{h}_t^2\right) + \tfrac{1}{2}U_{xx}X^2 \left(\hat{x}_t + \tfrac{1}{2}\hat{x}_t^2\right)^2$$

$$+\tfrac{1}{2}U_{hh}h^2 \left(\hat{h}_t + \tfrac{1}{2}\hat{h}_t^2\right)^2 + U_x X \left(\hat{x}_t + \tfrac{1}{2}\hat{x}_t^2\right)\left(\hat{z}_t + \tfrac{1}{2}\hat{z}_t^2\right) \tag{19}$$

$$+U_h h \left(\hat{h}_t + \tfrac{1}{2}\hat{h}_t^2\right)\left(\hat{z}_t + \tfrac{1}{2}\hat{z}_t^2\right) + t.i.p.$$

$$U_t - U \approx \hat{x}_t (1 + \hat{z}_t) - h^{\omega+1}\left[(1 + \hat{z}_t)\hat{h}_t + \frac{1+\omega}{2}\hat{h}_t^2\right] + t.i.p. \tag{20}$$

Now, we need to relate labor supply to output,

$$h_t = \frac{Y_t}{A_t}\int_0^1 \left(\frac{P_t(i)}{P_t}\right)^{-\varepsilon} di \tag{21}$$

which becomes

$$\hat{h}_t = \hat{y}_t - \hat{a}_t + \ln\left[\int_0^1 \left(\frac{P_t(i)}{P_t}\right)^{-\varepsilon} di\right] \tag{22}$$

The goal here is to rewrite $\ln\left[\int_0^1 \left(\frac{P_t(i)}{P_t}\right)^{-\varepsilon} di\right]$. Start by noticing that

$$\left(\frac{P_t(i)}{P_t}\right)^{1-\varepsilon} = \exp\left\{(1-\varepsilon)\hat{p}_t(i)\right\} \tag{23}$$

$$= 1 + (1-\varepsilon)\hat{p}_t(i) + \frac{(1-\varepsilon)^2}{2}\hat{p}_t(i)^2 \tag{24}$$

where $\hat{p}_t(i) \equiv [\ln P_t(i) - \ln(P_t)]$. Note that the definition of P_t implies that

$$1 = \int_0^1 \left(\frac{P_t(i)}{P_t}\right)^{1-\varepsilon} di \tag{25}$$

Therefore, by integrating both sides of the last expression gives

$$E_i[\hat{p}_t(i)] = \frac{\varepsilon - 1}{2}E_i\left[\hat{p}_t(i)^2\right] \tag{26}$$

Similarly, a second order approximation of $\left(\frac{P_t(i)}{P_t}\right)^{-\varepsilon}$ gives

$$\left(\frac{P_t(i)}{P_t}\right)^{-\varepsilon} = 1 - \varepsilon \hat{p}_t(i) + \frac{1}{2}\varepsilon^2 \hat{p}_t(i)^2 \tag{27}$$

Therefore, combining the two previous results in equations (26) and (27) gives

$$\int_0^1 \left(\frac{P_t(i)}{P_t}\right)^{-\varepsilon} = 1 - \varepsilon E_i \hat{p}_t(i) + \frac{1}{2}\varepsilon^2 E_i \hat{p}_t(i)^2 \tag{28}$$

$$= 1 + \frac{\varepsilon}{2} E_i \left[\hat{p}_t(i)^2\right] = 1 + \frac{\varepsilon}{2} var\{p_t(i)\} \tag{29}$$

where the last step follows from the definition of

$$\int_0^1 (p_t(i) - p_t)^2 \, di \approx \int_0^1 (p_t(i) - E_i p_t(i))^2 \, di \equiv var_i\{p_t(i)\} \tag{30}$$

Going back to (34), we can rewrite it as follows

$$\hat{h}_t \approx \hat{y}_t - \hat{a}_t + \frac{\varepsilon}{2} var\{p_t(i)\} \tag{31}$$

Replacing $\hat{h}_t \approx \hat{y}_t - \hat{a}_t + \frac{\varepsilon}{2} var\{p_t(i)\}$, and ignoring terms of order higher than 2, gives

$$\begin{aligned} U_t - U \approx \hat{x}_t(1+\hat{z}_t) - h^{\omega+1}\Big[&(1+\hat{z}_t)\left(\hat{y}_t - \hat{a}_t + \tfrac{\varepsilon}{2} var\{p_t(i)\}\right) \\ &+ \tfrac{1+\omega}{2}\left(\hat{y}_t - \hat{a}_t + \tfrac{\varepsilon}{2} var\{p_t(i)\}\right)^2 \Big] + t.i.p. \end{aligned} \tag{32}$$

$$U_t - U \approx \hat{x}_t(1+\hat{z}_t) - h^{\omega+1}\left[(1+\hat{z}_t)\hat{y}_t + \frac{\varepsilon}{2} var\{p_t(i)\} + \frac{1+\omega}{2}(\hat{y}_t - \hat{a}_t)^2\right] + t.i.p. \tag{33}$$

Normalize by $U_c C = \frac{1-\eta\beta}{1-\eta}$,

$$\frac{U_t - U}{U_c C} \approx \left(\frac{1-\eta}{1-\eta\beta}\right)\hat{x}_t(1+\hat{z}_t) - \left[(1+\hat{z}_t)\hat{y}_t + \frac{\varepsilon}{2} var\{p_t(i)\} + \frac{1+\omega}{2}(\hat{y}_t - \hat{a}_t)^2\right] + t.i.p. \tag{34}$$

Therefore, if we denote welfare by $\mathbb{W} = \sum_{t=0}^{\infty} \beta^t \left(\frac{U_t - U}{U_c C}\right)$, then

$$\mathbb{W} \approx \sum_{t=0}^{\infty} \beta^t \left[\left(\frac{1-\eta}{1-\eta\beta} \right) \hat{x}_t \left(1+\hat{z}_t\right) - \left[\left(1+\hat{z}_t\right) \hat{y}_t + \frac{\varepsilon}{2} var\left\{p_t\left(i\right)\right\} + \frac{1+\omega}{2} \left(\hat{y}_t - \hat{a}_t\right)^2 \right] \right]$$

$$\mathbb{W} \approx \sum_{t=0}^{\infty} \beta^t \left[\left(\frac{(1-\eta)}{(1-\eta\beta)} \hat{x}_t - \hat{y}_t \right) \left(1+\hat{z}_t\right) \right] - \sum_{t=0}^{\infty} \beta^t \left[\frac{\varepsilon}{2} var\left\{p_t\left(i\right)\right\} + \frac{1+\omega}{2} \left(\hat{y}_t - \hat{a}_t\right)^2 \right] \tag{35}$$

Now, express $\hat{x}_t$ in consumption terms:

$$\hat{x}_t = \ln\left(X_t/X\right) = \ln\left(\left(C_t - \eta C_{t-1}\right) / \left(\left(1-\eta\right)C\right)\right) = \ln\left(C_t - \eta C_{t-1}\right) - \ln\left(\left(1-\eta\right)C\right) \tag{36}$$

which, up to second order, is approximated to

$$\hat{x}_t \approx \tfrac{1}{1-\eta}\left(\tfrac{C_t - C}{C}\right) - \tfrac{\eta}{1-\eta}\left(\tfrac{C_{t-1}-C}{C}\right) - \tfrac{1}{2}\tfrac{1}{(1-\eta)^2}\left(\tfrac{C_t-C}{C}\right)^2$$

$$-\tfrac{1}{2}\tfrac{\eta^2}{(1-\eta)^2}\left(\tfrac{C_{t-1}-C}{C}\right)^2 + \tfrac{\eta}{(1-\eta)^2}\left(\tfrac{C_t-C}{C}\right)\left(\tfrac{C_{t-1}-C}{C}\right)$$

$$\hat{x}_t \approx \tfrac{1}{1-\eta}\left(\hat{c}_t + \tfrac{1}{2}\hat{c}_t^2\right) - \tfrac{\eta}{1-\eta}\left(\hat{c}_{t-1} + \tfrac{1}{2}\hat{c}_{t-1}^2\right) - \tfrac{1}{2}\tfrac{1}{(1-\eta)^2}\left(\hat{c}_t + \tfrac{1}{2}\hat{c}_t^2\right)^2$$

$$-\tfrac{1}{2}\tfrac{\eta^2}{(1-\eta)^2}\left(\hat{c}_{t-1} + \tfrac{1}{2}\hat{c}_{t-1}^2\right)^2 + \tfrac{\eta}{(1-\eta)^2}\left(\hat{c}_t + \tfrac{1}{2}\hat{c}_t^2\right)\left(\hat{c}_{t-1} + \tfrac{1}{2}\hat{c}_{t-1}^2\right)$$

$$\hat{x}_t \approx \frac{1}{1-\eta}\left(\hat{c}_t + \frac{1}{2}\hat{c}_t^2\right) - \frac{\eta}{1-\eta}\left(\hat{c}_{t-1} + \frac{1}{2}\hat{c}_{t-1}^2\right) - \frac{1}{2}\frac{1}{(1-\eta)^2}\left(\hat{c}_t^2 + \eta^2\hat{c}_{t-1}^2 - 2\eta\hat{c}_t\hat{c}_{t-1}\right)$$

$$\hat{x}_t \approx \frac{1}{1-\eta}\left(\hat{c}_t + \frac{1}{2}\hat{c}_t^2\right) - \frac{\eta}{1-\eta}\left(\hat{c}_{t-1} + \frac{1}{2}\hat{c}_{t-1}^2\right) - \frac{1}{2}\frac{1}{(1-\eta)^2}\left(\hat{c}_t - \eta\hat{c}_{t-1}\right)^2 \tag{37}$$

and, replaced back into equation (35) gives

$$\begin{aligned} \mathbb{W} \approx \textstyle\sum_{t=0}^{\infty} \beta^t \left[\left(\tfrac{\eta}{(1-\eta\beta)}\left(\beta\hat{y}_t - \hat{y}_{t-1}\right) - \tfrac{1}{2}\tfrac{1}{(1-\eta\beta)}\tfrac{\eta}{(1-\eta)}\left(\hat{y}_t - \hat{y}_{t-1}\right)^2\right)\left(1+\hat{z}_t\right)\right] \\ - \textstyle\sum_{t=0}^{\infty} \beta^t \left[\tfrac{\varepsilon}{2} var\left\{p_t\left(i\right)\right\} + \tfrac{1+\omega}{2}\left(\hat{y}_t - \hat{a}_t\right)^2\right] \end{aligned} \tag{38}$$

Using the result from Woodford (2003, Ch. 6), we can rewrite $\sum_{t=0}^{\infty}\beta^t var_i\left\{p_t\left(i\right)\right\} = \sum_{t=0}^{\infty}\beta^t \frac{\theta}{(1-\beta\theta)(1-\theta)}\pi_t^2$,

$$\begin{aligned}\mathbb{W} \approx \textstyle\sum_{t=0}^{\infty}\beta^t \Big[&\left(\tfrac{\eta}{(1-\eta\beta)}\left(\beta\hat{y}_t-\hat{y}_{t-1}\right)-\tfrac{1}{2}\tfrac{1}{(1-\eta\beta)}\tfrac{\eta}{(1-\eta)}\left(\hat{y}_t-\hat{y}_{t-1}\right)^2\right)\left(1+\hat{z}_t\right)\\ &-\tfrac{\varepsilon}{2}\tfrac{\theta}{(1-\beta\theta)(1-\theta)}\pi_t^2-\tfrac{1+\omega}{2}\left(\hat{y}_t-\hat{a}_t\right)^2\Big]\end{aligned}$$

$$\begin{aligned}\mathbb{W} \approx -\tfrac{1}{2}\textstyle\sum_{t=0}^{\infty}\beta^t \Big[&\tfrac{-2\eta}{(1-\eta\beta)}\left(\beta\hat{y}_t-\hat{y}_{t-1}\right)\left(1+\hat{z}_t\right)+\tfrac{1}{(1-\eta\beta)}\tfrac{\eta}{(1-\eta)}\left(\Delta\hat{y}_t\right)^2\left(1+\hat{z}_t\right)\\ &+\tfrac{\varepsilon\theta}{(1-\beta\theta)(1-\theta)}\pi_t^2+\left(1+\omega\right)\left(\hat{y}_t-\hat{a}_t\right)^2\Big]\end{aligned} \tag{39}$$

Because we do not have technology shocks, the (welfare loss) function reduces to

$$\begin{aligned}\mathcal{L} \approx -\tfrac{1}{2}\textstyle\sum_{t=0}^{\infty}\beta^t \Big[&\underbrace{\frac{-2\eta}{(1-\eta\beta)}}_{\chi_1}\left(\beta\hat{y}_t-\hat{y}_{t-1}\right)\left(1+\hat{z}_t\right)+\underbrace{\frac{1}{(1-\eta\beta)}\frac{\eta}{(1-\eta)}}_{\chi_2}\Delta\hat{y}_t^2\left(1+\hat{z}_t\right)\\ &+\underbrace{\frac{\varepsilon\theta}{(1-\beta\theta)(1-\theta)}}_{\chi_3}\pi_t^2+\underbrace{(1+\omega)}_{\chi_4}\hat{y}_t^2\Big]\end{aligned}$$

where the period-t loss is given by

$$\mathcal{L}_t \approx -\frac{1}{2}\left[\left(\chi_1\left(\beta\hat{y}_t-\hat{y}_{t-1}\right)+\chi_2\Delta\hat{y}_t^2\right)\left(1+\hat{z}_t\right)+\chi_3\pi_t^2+\chi_4\hat{y}_t^2\right] \tag{40}$$