Monetary Policy and the COVID-19 Price Level Shock*

David Andolfatto[1] and Fernando M. Martin[2]

[1]Department of Economics, Miami Herbert Business School, University of Miami
[2]Research Division, Federal Reserve Bank of St. Louis

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Abstract

We employ a small-scale dynamic general equilibrium model to analyze the surge in inflation following the COVID-19 pandemic. A calibrated version of the model is used to assess U.S. monetary and fiscal policy over the 2020–2024 period and to estimate the economic and welfare consequences of alternative policy scenarios. The analysis suggests that the large fiscal transfers of 2020–2021 were broadly welfare-improving, albeit larger than necessary. Given the fiscal stance in place, optimal monetary policy would not have generated a materially different price level dynamic. While monetary policy could, in theory, have prevented the inflation surge through coordinated fiscal adjustment, this would have required a permanently higher real interest rate and a prolonged recession. The model estimates that observed monetary policy actions helped to moderate the inflation path but had only a limited effect on the cumulative increase in the price level. A fiscal anchor on inflation expectations implies that the COVID-19 era inflation episode would likely have been mean-reverting even without aggressive monetary tightening.

Keywords: monetary policy; fiscal policy; inflation; price level; COVID-19.

JEL codes: E40, E52, E60, E63, E65

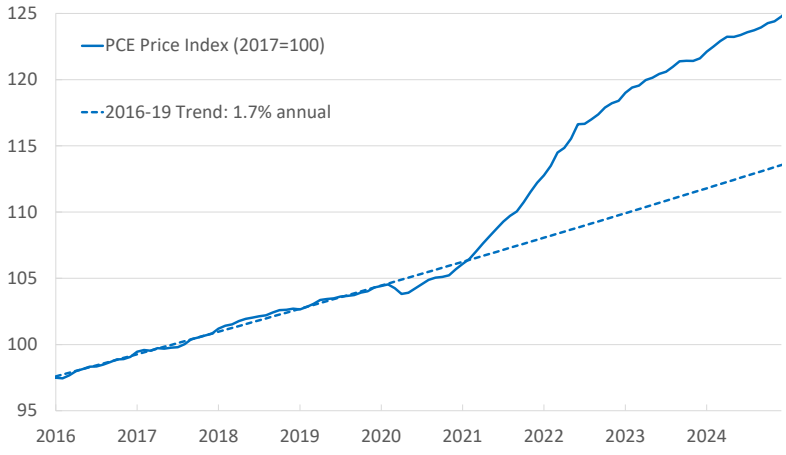
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1 Introduction

For most of the decade that followed the 2007-08 financial crisis, inflation remained below the Federal Reserve's two percent inflation target. Deflationary pressures remained evident into the spring of 2020 as the COVID-19 pandemic swept across the country in the midst of a policy-induced recession. Given this historical context, it is understandable that Americans were unprepared when inflation began to surge in spring 2021. Between 2021 and the summer of 2022, PCE inflation increased by approximately 500 basis points, reaching a peak of 7 percent year-over-year. The inflation surge proved to be temporary. Inflation declined rapidly from its peak in the summer of 2022, leaving the price level roughly 10 percent higher than its pre-pandemic trend; see Figure 1. We label this phenomenon the COVID-19 *price level shock*. This paper seeks to interpret this shock and evaluate the impact of both actual and hypothetical policy measures on inflation and recovery dynamics.

Many critics are quick to blame the Federal Reserve for failing to control inflation. In his 2024 Jackson Hole speech, Fed Chair Jerome Powell acknowledged that the Fed was slow to tighten monetary policy, largely because policymakers believed the initial inflation surge would prove "transitory" in the sense that price increases would rapidly reverse themselves without significant policy intervention. As inflation was initially concentrated in relatively few product categories driven by supply disruptions related to the COVID-19 pandemic, it was not unreasonable to expect these forces to reverse themselves in a relatively short period of time. Moreover, Powell points out that standard monetary policy doctrine supports ignoring temporary supply-induced inflation shocks. Nonetheless, inflation continued to accelerate and became broader-based, driven by factors such as pent-up demand, stimulative policies, pandemic-induced changes in work and leisure behaviors, and increased savings from constrained services spending—collectively fueling a historic surge in consumer spending on goods.

Figure 1: The COVID-19 Price Level Shock



Sources: Bureau of Economic Analysis and author's calculations.

By October 2021, inflation was no longer considered "transitory," prompting the Federal Reserve to begin shifting its policy stance. In November 2021, it started tapering asset purchases, followed by aggressive interest rate hikes beginning in March 2022. Russia's invasion of Ukraine in February 2022, along with persistent global

supply chain disruptions—exacerbated by pandemic-related restrictions in China and elsewhere—further intensified inflationary pressures. Although inflation eventually declined, it remains above pre-pandemic levels. Powell (2024) credits the Fed's actions with achieving a "soft landing" by stabilizing inflation expectations.

Even under this generous interpretation of Federal Reserve policy, the nearly year-long gap between the inflation surge in spring 2021 and the first policy rate hike in spring 2022 is difficult to overlook. Critics have argued that monetary tightening should have begun sooner. Were they right—did the Fed fall behind the curve? Could earlier action have prevented or at least mitigated the inflation surge of 2021–22? What might have been the broader economic consequences of earlier tightening? And how did fiscal policy influence the inflation dynamic that ultimately played out?

We address these and related questions using a dynamic general equilibrium model. The model is rich enough to capture the heterogeneous experiences of households during the pandemic, yet simple enough to clearly illustrate the key economic mechanisms at play. Our primary objective is to qualitatively assess both actual and counterfactual policy responses. To support this analysis, we parameterize and calibrate the model to U.S. data, allowing us to present our estimates and simulations in a visually intuitive manner.

The model incorporates two types of shocks. The first is a shock that affects the level and dispersion in household earnings, intended to capture the impact of policies that shut down specific sectors of the economy. By construction, this shock triggers a sharp recession, with its negative effects concentrated among a subset of households. In the absence of a "pandemic insurance market," fiscal policy plays a critical role in providing income support.

The second shock leads some households to postpone consumption and increase their desired savings. We interpret this as a reduced-form representation of both the limited availability of certain goods and services, and the rise in precautionary savings in response to heightened uncertainty. As such, this force operates like a negative demand shock.

We calibrate the model's impulse responses to match, at least approximately, the observed dynamics of shocks and policy actions during the pandemic period. Using this calibrated framework, we evaluate the actual policy response and conduct a series of counterfactual experiments. Because our model is a dynamic stochastic general equilibrium model, it allows us to characterize a socially efficient allocation—providing a benchmark against which we can assess the welfare implications of both actual and hypothetical policy responses.

Our counterfactual exercises explore how the economy would have evolved under the different scenarios and provide several insights. First, absent any policy response, the economy would have experienced a modest deflation and binding debt constraints. Second, an optimal deficit-financed policy would have loosened debt constraints with less inflation. Third, an optimal tax-financed policy would have loosened debt constraints with some deflation. Fourth, an optimal monetary policy conditional on observed fiscal policy would have tightened earlier with the effect of postponing the inflation surge. Fifth, a central bank could have unilaterally kept inflation pegged only by raising the real rate of interest asymptotically (unsustainably). Sixth, the manner in which inflation expectations are anchored matter for the interest rate policy needed to achieve a given price level dynamic. Lastly, a nominal interest rate peg would have implied a larger, but still transitory, inflation surge.

2 Literature Review

Our theoretical framework is based on the fiscal theory of the price level pioneered by Sargent and Wallace (1981), Aiyagari and Gertler (1985), Leeper (1991), Sims (1994), Woodford (1994), and Cochrane (2005). A central theme of this literature is that monetary-fiscal policies are inextricably linked through a consolidated government budget constraint, that monetary-fiscal policy regimes need to be modeled explicitly, and that the coordination of monetary and fiscal policy (or lack thereof) is important for interpreting historical data. The theory and arithmetic point to a decidedly more modest role for monetary policy and a correspondingly more significant role for fiscal policy in determining the price level and anchoring inflation.[1]

The 2021-22 surge in US inflation spawned a burgeoning literature trying to understand it. Given the prominent role of fiscal policy in this recent episode, it is not surprising to see several applications of the fiscal theory.[2] Bianchi, Faccini and Melosi (2023) develop a quantitative model and estimate it using US data. They find that unfunded government spending shocks account for the bulk of US inflation, including COVID-19 inflation. This finding is not uncontroversial. Smets and Wouters (2024), in contrast, estimate that over 80 percent of the fiscal implications of US business cycle shocks, including fiscal shocks, are funded. Nevertheless, they too find that expansionary fiscal policy contributed to higher inflation in 2021, consistent with what Barro and Bianchi (2025) find in a number of OECD countries. Bassetto and Miller (2025) develop a model in which individuals endogenously acquire information about the prevailing fiscal regime. Their model is used to understand why inflation surged in 2021-22 instead of rising steadily as one might expect if people only gradually recognized the unfunded nature of the COVID-19 deficits.

Although there is a growing consensus that fiscal policy played a significant role in shaping the recent inflation dynamic, relatively little attention has been paid to assessing normative aspects of monetary and fiscal policy during the episode. There is, of course, a large literature that casts inflationary finance in a negative light; e.g., see Hall and Sargent (2022*a*,*b*). But there is a public finance literature that casts inflation finance–in at least some circumstances–in a more favorable light; e.g., Chari and Kehoe (1999), Sims (2001), Lustig, Sleet and Yeltekin (2008), and more recently, Leeper and Zhou (2021). Our analysis interprets the recent inflation episode in the same light. However, we also consider counterfactual experiments that explore the properties of optimal monetary policy for a given (not necessarily optimal) fiscal policy. In this respect, our analysis is similar to Benigno and Woodford (2007), except applied to the COVID-19 inflation episode.

Our analysis builds on insights from the literature cited above and leads to three main conclusions: (1) the COVID-19 price level shock was primarily driven by an unfunded fiscal spending shock; (2) although possibly excessive, this fiscal intervention was nonetheless welfare-improving; and (3) there was little, if anything, the Federal Reserve could have done on its own to prevent the resulting rise in the price level.

[1] More recent explorations of the fiscal theory include Leeper and Leith (2016), Bassetto and Cui (2018), Andolfatto and Martin (2018), Cochrane (2022), Caramp and Silva (2023).

[2] More traditional monetarist explanations have also been put forward, for example, Gao and Nicolini (2023).

3 The Environment

Let $t = 1, 2, ..., \infty$ denote time. The economy is populated by overlapping generations of households. There is an initial old population that lives for one period only. On every date $t \geq 1$, a new generation of young households enters the economy expecting to participate for two periods. At any given date, a constant population is evenly divided between young and old generations. The size of each new generation is normalized to equal a unit mass.

Households have preferences defined over lifetime consumption. Let c_t^y, c_t^o denote consumption at date t by the young and old, respectively. A young type $j \in \{L, H\}$ household has preferences

$$U_t(j) = E_t[(1 - \alpha_t)/(1/\beta_j)u(c_t^y) + c_{t+1}^o] \tag{1}$$

where $\beta_H > \beta_L > 0$, $u'' < 0 < u'$, and E_t is an expectation operator conditional on information available at date t. Let $0 < \rho < 1$ denote the fraction of *ex ante* impatient households; i.e., those households with $\beta_L < \beta_H$. The parameter $0 \leq \alpha_t \leq 1$ is an aggregate shock determining the *ex post* patience of long-horizon decision makers (i.e., young households). A larger realization of α_t reflects a greater desire to delay consumption. The desire to delay consumption in this context can be thought of as emanating from a variety of sources. For example, during a pandemic, fear of contracting the virus may lead some households to temporarily postpone their shopping excursions. It could also capture an increased desire on the part of some households to delay spending activities because of a need to reallocate time to care for sick relatives.

The primary source of income for young households is their labor earnings, which we model here as exogenous. When the COVID-19 pandemic arrived in the United States early in 2020, it unleashed a host of forces that negatively impacted the earnings capacity of many, though not all, American households. We model this phenomenon as follows. There are two levels of real earnings, $w_t(l) < w_t(h)$. At each date t, a fraction $0 \leq \sigma_t \leq 1$ of impatient young households experience a negative earnings shock, resulting in earnings $w_t(l) < w_t(h)$. We also allow for independent exogenous variation in $\{w_t(l), w_t(h)\}$. In this way, a recession is characterized by both its impact on average earnings and its effect on the dispersion of earnings between workers. The exogenous stochastic process that governs the evolution of $\{w_t(h), w_t(l), \sigma_t\}$ generates aggregate and idiosyncratic uncertainty. There is idiosyncratic uncertainty because impatient young workers do not know beforehand whether they will be assigned to the high- or low-wage categories; all they know is that a fraction σ_t will be assigned to the low-wage category. Assume that all shocks are realized at the beginning of period t. Aggregate earnings at date t are given by

$$w_t \equiv (1 - \rho)w_t(h) + \rho[\sigma_t w_t(l) + (1 - \sigma_t)w_t(h)] \tag{2}$$

As in Diamond (1965), there is a technology to transform current output into future output. For simplicity, we assume that this investment technology is operated directly by households. Each young household has access to an investment project that transforms k_t units of output at date t into $f(k_t)$ units of output at date $t + 1$, where $f'' < 0 < f'$. Also, for simplicity, assume that capital investment depreciates fully after it is used in production. We assume that the pandemic shock has no direct effect on investment technology.

The economy wide resource constraint is given by,

$$\rho[c_t^y(L) + c_t^o(L)] + (1 - \rho)[c_t^y(H) + c_t^o(H)] + k_t \leq w_t + f(k_{t-1}) \tag{3}$$

for all $t \geq 1$ and with $k_0 \geq 0$ given.

3.1 Efficient Allocation

We assume a social welfare function $W = E_1 \sum_{t=0}^{\infty} \delta^t \{\rho U_t(L) + (1-\rho) U_t(H)\}$, where $U_0(j) = c_1^o(j)$. That is,

$$W = E_1 \sum_{t=1}^{\infty} \delta^t \Big\{ \rho[(1-\alpha_t)(1/\beta_L) u(c_t^y(L)) + (1/\delta) c_t^o(L)] \\ + (1-\rho)[(1-\alpha_t)(1/\beta_H) u(c_t^y(H)) + (1/\delta) c_t^o(H)] \Big\}$$

where $0 < \delta < 1$ is introduced simply as a device to bound W. A planner interested in maximizing W subject to the sequence of period resource constraints would choose allocations that satisfy the following conditions on a period-by-period basis (after taking $\delta \to 1$,):

$$(1-\alpha_t) u'(\hat{c}_t^y(L)) = \beta_L; \quad (4)$$

$$(1-\alpha_t) u'(\hat{c}_t^y(H)) = \beta_H; \quad (5)$$

$$f'(\hat{k}_t) = 1; \quad (6)$$

in addition to the resource constraint (3) for all $t \geq 1$ with $k_0 \geq 0$ given.[3]

The restriction to quasilinear preferences buys us much in the way of analytical tractability. First, the optimal allocation can be characterized without reference to the exact properties of the stochastic properties that govern the shock processes. This restriction also implies that it is efficient for old households to perfectly insure young households against their earnings risk (both idiosyncratic and aggregate risk). Specifically, $\{c_t^y(j)\}$ for $j = L, H$ are independent of all shocks to earnings $\{w_t(l), w_t(h), \sigma_t\}$. Finally, quasilinearity implies that the efficient level of capital spending is independent of all earning and preference shocks.

Thus, it is efficient to stabilize investment and insure young households against any loss of income attributable to the pandemic. In this case, the planner would want to divert resources from the old to the young. On the other hand, if the pandemic is also associated with an increased desire to delay consumption, the efficient transfer of purchasing power runs from young to old.[4]

The analysis above provides us with a guide to help evaluate the properties of an efficient allocation and how it should respond to a pandemic shock. An important takeaway from this analysis is that *nobody* should be better off when a pandemic hits. In other words, it is desirable to spread the pain across all members of the community. The pain itself is unavoidable. The planner must ask who in society is best able to absorb the pain and how. The same question should be asked by policymakers.

Our next task is to decentralize the economy and characterize the equilibrium allocation as a function of shocks and policies. Although we are primarily interested in using the model to evaluate the conduct of monetary policy for a given fiscal policy, we can ask a number of other interesting questions along the way. In particular, how can a decentralized economy be expected to absorb the shock of a pandemic? Do resources flow in the direction our planner above would dictate? Can we identify the properties of monetary-fiscal policies that help support efficient implementation? How do these policies compare to observed policies?

[3] Note that $\hat{c}_t^o < 0$ is permissible here since utility is transferable (think of negative consumption as labor effort). See Appendix A for a detail of the derivations of (4)–(6).

[4] Of course, the labels *young* and *old* here should be taken as metaphors for people who, respectively, derive their purchasing power primarily from labor or financial wealth.

4 A Monetary Economy

4.1 Market Structure

Let p_t denote the price level at date t. Assume a sequence of competitive spot markets where goods trade for money at prices $\{p_t : t \geq 1\}$. Define inflation at date t as the growth rate in the price level with respect to the preceding period, i.e., $\Pi_t \equiv p_t/p_{t-1}$.

4.2 Government Policy

Let G_t denote government spending on goods and services. Let T_t denote tax revenue and let Z_t denote money transfers to households. Let M_{t-1} denote the stock of nominally risk-free debt of one period that is due at the beginning of period t. Let R_{t-1} denote the gross nominal interest rate paid on government debt. Government revenues and expenditures must satisfy,

$$T_t + M_t = G_t + Z_t + R_{t-1}M_{t-1} \tag{7}$$

Equation (7) says that the interest expense of the debt, $(R_{t-1}-1)M_{t-1}$, must be financed through some combination of the primary budget surplus $T_t - Z_t - G_t$ and new debt $M_t - M_{t-1}$. For simplicity, we set $G_t = 0$ for all t. Assume that the interest expense of the debt is financed through taxes and debt, while transfers are financed exclusively through debt; i.e.,

$$\begin{aligned} T_t &= \theta_t(R_{t-1} - 1)M_{t-1} && (8)\\ M_t - M_{t-1} &= Z_t + (1 - \theta_t)(R_{t-1} - 1)M_{t-1} && (9) \end{aligned}$$

where $\theta_t \in [0, 1]$. When $\theta_t = 0$, both transfers and interest expense are financed exclusively with debt. When $\theta_t = 1$, all interest expense is financed with taxes, while transfers are financed with debt.

Monetary policy is determined by the interest rate rule,

$$R_t = r_t E_t \Pi_{t+1} \tag{10}$$

where r_t is a monetary policy variable and $E_t\Pi_{t+1}$ is the rate of inflation expected by households. Let r^* and Π^* be the long-run targets for the real interest and inflation rates, respectively.

4.3 Household Decisions

Let $\{c_t^y(i,j), c_{t+1}^o(i,j)\}$ denote the lifetime consumption profile of a type $(i,j) \in \{l,h\} \times \{L,H\}$ household entering the economy at date t. Recall that only impatient (L) households may experience the low-earnings shock, σ_t. Hence, there are no households of type (l,H).

A young type-(i,j) household faces the following sequence of budget constraints,

$$\begin{aligned} p_t c_t^y(i,j) &= p_t w_t(i) - m_t(i,j) - p_t k_t(i,j) + Z_t(i) && (11)\\ p_{t+1} c_{t+1}^o(i,j) &= p_{t+1} f(k_t(i,j)) + R_t m_t(i,j) - T_{t+1} && (12) \end{aligned}$$

where $m_t(i,j) \geq 0$ denotes the household's accumulation of government securities, $Z_t(i)$ denotes a government transfer, and T_t denotes a lump-sum tax. Note that government

transfers may depend on earnings, but not on the degree of impatience. Importantly, there are no private insurance markets.

Define $q_t \equiv m_t/p_t$, $z_t(i) \equiv Z_t(i)/p_t$, $\tau_t \equiv T_t/p_t$ and use these expressions to rewrite the system above in real terms,

$$\begin{aligned} c_t^y(i,j) &= w_t(i) - q_t(i,j) - k_t(i,j) + z_t(i) \quad (13) \\ c_{t+1}^o(i,j) &= f(k_t(i,j)) + R_t/\Pi_{t+1} q_t(i,j) - \tau_{t+1} \quad (14) \end{aligned}$$

Substituting (13) and (14) into the household's objective function (1) yields,

$$\begin{aligned} U_t(i,j) &= (1-\alpha_t) u(w_t(i) - q_t(i,j) - k_t(i,j) + z_t(i)) \\ &+ \beta_j E_t[f(k_t(i,j)) + R_t/\Pi_{t+1} q_t(i,j) - \tau_{t+1}] + \lambda_t(i,j) q_t(i,j) \end{aligned}$$

where $\lambda_t(i,j)$ is the Lagrange multiplier associated with the non-negativity constraint, $q_t(i,j) \geq 0$. This non-negativity constraint can be expected to bind for some types in a severe recession.

Necessary conditions characterizing optimal household behavior $\{q_t(i,j), k_t(i,j)\}$ are given by

$$\begin{aligned} (1-\alpha_t) u'(w_t(i) - q_t(i,j) - k_t(i,j) + z_t(i)) &= \beta_j R_t E_t[1/\Pi_{t+1}] + \lambda_t(i,j) \quad (15) \\ (1-\alpha_t) u'(w_t(i) - q_t(i,j) - k_t(i,j) + z_t(i)) &= \beta_j f'(k_t(i,j)) \quad (16) \end{aligned}$$

for $i = \{l, h\}$ and $j = \{L, H\}$.

4.4 Equilibrium

Combining (10), (15) and (16) implies,

$$f'(k_t(i,j)) = r_t E_t \Pi_{t+1} E_t[1/\Pi_{t+1}] + \lambda_t(i,j)/\beta_j \quad (17)$$

for $i = \{l, h\}$ and $\{j = L, H\}$. With $q_t(i,j)$ and $k_t(i,j)$ determined by (16), (17) and the complementary slackness condition, $\lambda_t(i,j) q_t(i,j) = 0$, the corresponding consumption demands are given by,

$$\begin{aligned} c_t^y(i,j) &= w_t(i) - q_t(i,j) - k_t(i,j) + z_t(i) \quad (18) \\ c_t^o(i,j) &= f(k_{t-1}(i,j)) + R_{t-1}/\Pi_t q_{t-1}(i,j) - \tau_t \quad (19) \end{aligned}$$

for $i = \{l, h\}$ and $j = \{L, H\}$ for all $t \geq 1$.

In equilibrium, the supply of nominal securities M_t/p_t must equal the demand for real balances, Q_t,

$$M_t/p_t = Q_t \quad (20)$$

for all $t \geq 1$, where Q_t consists of a weighted sum of individual money demands,

$$Q_t \equiv (1-\rho) q_t(h,H) + +\rho[\sigma_t q_t(l,L) + (1-\sigma_t) q_t(h,L)] \quad (21)$$

Let $\mu_t \equiv M_t/M_{t-1}$ be the growth rate of the supply of nominal securities. From (20) we can derive the following expression for the inflation rate,

$$\Pi_t = \mu_t Q_{t-1}/Q_t \quad (22)$$

Inflation depends negatively (positively) on current (past) demand for real balances.

We assume that transfers, $z_t(i)$, and fiscal support, θ_t, are fiscal policy parameters. Hence, taxes, τ_t, and the growth rate of nominal liabilities, μ_t, evolve endogenously. From the government budget rules (8) and (9), plus the market-clearing condition (20), we can write:

$$\tau_t = \theta_t(R_{t-1}-1)(Q_t/\mu_t) \tag{23}$$

$$\mu_t = \frac{Q_t[1+(1-\theta_t)(R_{t-1}-1)]}{Q_t - z_t} \tag{24}$$

where $z_t \equiv \rho\sigma_t z_t(l) + (1-\rho\sigma_t)z_t(h)$.

Using (24) to substitute out μ_t in (22) and (23) implies

$$\Pi_t = \frac{Q_{t-1}[1+(1-\theta_t)(R_{t-1}-1)]}{Q_t - z_t} \tag{25}$$

$$\tau_t = \frac{\theta_t(R_{t-1}-1)(Q_t - z_t)}{1+(1-\theta_t)(R_{t-1}-1)} \tag{26}$$

Transfers have a direct effect on inflation and taxes, but also an indirect effect through the demand for real balances.

4.5 Efficient policy

When comparing equilibrium conditions (16) and (17) with the conditions characterizing the efficient allocation, (4)–(6), it follows that, to implement an efficient allocation, government policy must relax debt constraints and target the appropriate real interest rate. Debt constraints are slack when $\lambda_t(i,j) = 0$ for all (i,j). Because there is no population or productivity growth, the (gross) "natural" real rate of interest in this environment is equal to one.

When debt-constraints are slack and the marginal product of capital is equal to one, (17) implies the real interest rate must satisfy,

$$r_t = \{E_t\Pi_{t+1}E_t[1/\Pi_{t+1}]\}^{-1} \tag{27}$$

Under this policy, (16) and (17) become

$$(1-\alpha_t)u'(c_t^y(i,j)) = \beta_j \tag{28}$$

$$f'(k_t(i,j)) = 1 \tag{29}$$

which imply $k_t(i,j) = \hat{k}_t$ and $c_t^y(i,j) = \hat{c}_t(j)$. From (18) we obtain

$$q_t(i,j) = w_t(i) + z_t(i) - \hat{k}_t - \hat{c}_t^y(j) \tag{30}$$

Any transfer scheme $z_t(i)$ that implements $q_t(i,j) \geq 0$ for all (i,j) implements the efficient allocation. Transfers sent to young households in excess of those required to relax debt constraints are simply saved. As shown in Appendix A, due to our assumption of quasilinear preferences, the planner's problem only pins down average consumption when old, not how it is distributed across impatient and patient households. Hence, different transfer schemes, as long as debt constraints remain slack, correspond to different planner allocations for the old across types (the average remains the same). This property implies that multiple inflation rates (resulting from different transfer schemes) are consistent with the efficient allocation.

4.6 Steady state

Suppose there are no shocks and that government policy implements the long-run targets, $\{r^*, \Pi^*, \theta^*\}$. Assume $\alpha_t = \sigma_t = 0$ and $w_t(h) = w(h) = w$. Since there are no l-type households, agents in steady state are either impatient (L) or patient (H). All young households receive the same transfers, z.

The steady state allocation $\{c^y(j), c^o(j), q(j), k(j), \lambda(j)\}_{j=\{L,H\}}$ is characterized by

$$\begin{aligned} u'(w - q(j) - k(j) + z) &= \beta_j f'(k(j)) \\ f'(k(j)) &= r^* + \lambda(j)/\beta_j \\ c^y(j) &= w - q(j) - k(j) + z \\ c^o(j) &= f(k(j)) + r^* q(j) - \tau \end{aligned}$$

and $\lambda(j)q(j) = 0$, for $j = \{L, H\}$.

Let $Q \equiv (1-\rho)q(H) + \rho q(L)$. From (25) we obtain

$$\Pi = \frac{Q[1 + (1-\theta^*)(r^*\Pi^* - 1)]}{Q - z}$$

Importantly, steady state inflation is determined by both fiscal and monetary policies. Fiscal policy affects the long-run inflation rate through transfers, z. Monetary policy affects the long-run inflation rate through the real interest rate, r which, together with transfers, z, determines the demand for real balances, Q.

Assume that fiscal policy is consistent with the inflation target, i.e., let z be set so that $\Pi = \Pi^*$. Then,

$$\begin{aligned} \mu &= \Pi^* \\ z &= \left[1 - (1-\theta^*)r^* - \theta^*/\Pi^*\right] Q \\ \tau &= \theta^*(r^* - 1/\Pi^*)Q \end{aligned}$$

When $r^* = \Pi^* = 1$ we obtain, $\mu = 1$ and $z = \tau = 0$. For this steady state to be efficient, it must be the case that earnings are large enough so that debt constraints do not bind. Specifically, $w \geq \hat{c}^y(L) + \hat{k}$.

5 Equilibrium under adaptive expectations

In this section, we will derive some important analytical results under the assumption that households form inflation expectations using an adaptive rule, anchored at the long-run inflation target. Hence, expectations will react less than one-to-one with observed inflation. This assumption has several complementary purposes. First, it will allows us to further characterize the properties of the monetary equilibrium and establish the implications on inflation of policy changes and aggregate shocks. Second, it captures the behavior of actual inflation expectations, which trailed actual inflation since the onset of the pandemic, but in a muted manner. As such, it will the working assumption in our quantitative analysis in later sections. Third, in combination with the assumption of quasi-linear preferences, adaptive expectations allow us to characterize household decisions during the pandemic solely as functions of current policy, without having to specify household beliefs about the evolution of the pandemic or future government policy.

5.1 Household Expectations

We assume that households form expectations as follows. Consider a stochastic process $\{x_t\}$ with an unconditional mean x. Then

$$E_t x_{t+1} = x_t^{1-\phi} x^{\phi} \tag{31}$$

where $0 \leq \phi \leq 1$. Applying this protocol to inflation expectations when the unconditional mean of inflation is equal to the inflation target, we have

$$E_t \Pi_{t+1} = \Pi_t^{1-\phi} (\Pi^*)^{\phi} \tag{32}$$

The parameter $0 \leq \phi \leq 1$ here governs how strongly household inflation expectations react to inflation data. The same parameter also governs how strongly monetary policy reacts to inflation data via equation (10). In particular, combining (10) with (32) and noting that $\Pi^* = 1$ implies

$$R_t = r_t \Pi_t^{1-\phi} \tag{33}$$

We apply the same protocol to expected inverse inflation, which is the relevant object in the household's optimality conditions. We obtain,

$$E_t[1/\Pi_{t+1}] = (1/\Pi_t)^{1-\phi} E[1/\Pi]^{\phi}$$

where $E[1/\Pi]$ is the unconditional mean of the inverse of inflation. Since we assume $E[\Pi] = \Pi^* = 1$ we obtain $E[1/\Pi] = 1/\Pi^* = 1$. Hence,

$$E_t[1/\Pi_{t+1}] = (1/\Pi_t)^{1-\phi} \tag{34}$$

Under these assumptions, the household's Euler equation (17) becomes

$$f'(k_t(i,j)) = r_t + \lambda_t(i,j)/\beta_j \tag{35}$$

for $i = \{l, h\}$ and $j = \{L, H\}$. Hence, we can characterize the equilibrium outcomes in period t as functions of the real interest rate r_t, real transfers $z_t(i)$ and fiscal support, θ_t.

5.2 Effects of policy

The following proposition states the effects of fiscal and monetary policy on households' decisions. We consider the impact of a change in current transfers, z_t, and the real interest rate, r_t, on the consumption and savings decisions of the current generation of young households, $c^y(i,j)$, $q_t(i,j)$ and $k_t(i,j)$. The effects of policy changes depend on whether households are debt-constrained or not. All proofs are in Appendix B.

Proposition 1. ***Effects of Fiscal and Monetary Policies on Young Households***

a. An increase in real transfers:

(i) for unconstrained young households, has no effect on consumption or capital investment, and is fully saved in real balances;

(ii) for constrained young households, increases consumption and capital investment.

b. An increase in the real interest rate:

(i) for unconstrained young households, decreases consumption and capital investment and increases holdings of real balances;

(ii) for constrained young households, has no effect.

The effects of fiscal and monetary policies vary depending on whether young households are debt-constrained or not. First, consider the case when all young households are unconstrained. An increase in real transfers is fully saved and thus, implies an increase in the demand for real balances; there is no effect on consumption or capital investment. An increase in the real interest rate leads to the classic Tobin effect: a decrease in consumption and capital investment, and an increase in the demand for real balances.

Second, suppose there are some constrained young households. An increase in real transfers allows these households to increase their consumption and capital investment, closer to optimal levels. In this case, fiscal policy has real effects on aggregate consumption and investment. In contrast, a change in the real interest rate has no impact on constrained households. Thus, the effects of monetary policy propagate through their impact on unconstrained young households' decisions, as described above.

We now turn to the effects of fiscal and monetary policies, z_t and r_t, respectively, on current and future inflation. We focus on one-time changes to transfers and the real interest rate, that revert in the following period. The starting point is an economy where all young households are unconstrained and there are no transfers. These circumstances will also characterize the initial conditions in our quantitative analyses below. These assumptions can be relaxed and we discuss the impact of this whenever relevant.

Proposition 2. ***Effects of Fiscal and Monetary Policies on Inflation***

Consider an equilibrium in which all young households are unconstrained and transfers are zero, i.e., $\lambda_t(i,j) = 0$ *for* $i = \{l,h\}$, $j = \{L,H\}$ *and* $z_t = 0$, *for all* $t \geq 1$.

a. A one-time increase in real transfers has no impact on current inflation, $d\Pi_t/dz_t = 0$, *and increases inflation in the following period,* $d\Pi_{t+1}/dz_t > 0$.

b. A one-time increase in the real interest rate decreases current inflation, $d\Pi_t/dr_t < 0$, *and increases inflation in the following period,* $d\Pi_{t+1}/dr_t > 0$.

Transfers are inflationary. An important property of our model is that, when all young households are unconstrained, the price-level effects of an expansionary fiscal policy are not felt on impact, but rather in subsequent periods. Specifically, the inflationary impact is delayed by one period. The reason is that unconstrained households save all the transfers they receive: the increase in the demand for real balances perfectly offsets the increase in the real supply of debt (which finances the increase in real transfers). In the following period, the demand for real balances returns to its previous level, while the (nominal) supply remains elevated. Hence, the price level increases to clear the market.

As shown in Proposition 1, transfers going to constrained young households would have no impact on their demand for real balances. Hence, the associated expansion in nominal liabilities, used to finance the transfers to constrained households, would have a positive impact on current (as well as future) inflation.

On impact, an increase in the real interest rate is deflationary. The channel is a Tobin-style substitution effect. Government debt becomes more attractive and hence, the demand for real balances increases, which leads to a drop in the price level. This effect reverts in the following period and inflation consequently increases.

The impact of the real interest rate on future inflation can be persistent when at least some of the interest expense is financed with debt rather than taxes, i.e., when $\theta_{t+1} < 1$. In such a case, the higher nominal interest rate in t results in an expansion of nominal liabilities in $t+1$ (the fraction of interest expenses financed with debt rather than taxes), which increases the inflationary impact in $t+1$. This channel is still active in subsequent periods, adding persistence to the impact of changes in the current real interest rate on future inflation.

5.3 Inflation targeting

Modern central banks have adopted inflation-targeting strategies to pursue their price stability mandate. Here, we can let monetary policy set the real rate, r_t, to implement inflation equal to target, conditional on adequate fiscal support. In Section 4.6 we showed how the long run inflation rate depends on both fiscal and monetary policies. Proposition 2 showed that debt-financed fiscal expansions (here, an increase in real transfers) are inflationary. Now, we shall analyze how (and whether) monetary policy can unilaterally maintain inflation at target when facing a fiscal expansion.

Condition (25) implicitly determines the demand for real balances consistent with maintaining inflation at target, Q_t^*. When $\Pi_t = \Pi^* = 1$ we obtain,

$$Q_t^* = z_t + Q_{t-1}[1 + (1 - \theta_t)(R_{t-1} - 1)] \tag{36}$$

Suppose we start from initial conditions consistent with a steady state with inflation at target and all households unconstrained. From Section 4.6, we get $r^* = 1$, $z = \tau = 0$. Note that $R^* = r^*\Pi^* = 1$. Let Q^* be the corresponding demand for real balances. Suppose there is a one-time increase in real transfers in the first period, i.e., $z_1 = \zeta > 0$ and $z_t = 0$ for $t > 1$. Then, (36) implies

$$Q_1^* = \zeta + Q^* \tag{37}$$

As shown in Proposition 2, a one-time increase in real transfers to unconstrained young households is fully saved in real balances and does not increase current inflation, i.e., $\Pi_1 = 1$. Thus, on impact, monetary policy remains unchanged, $r_1 = 1$. What happens afterwards depends on fiscal support, θ_t.

Full fiscal support

When $\theta_t = 1$, all interest expense is financed with taxes. Then, given $z_2 = 0$, (36) and (37) imply $Q_2^* = \zeta + Q^*$. Note that $Q_2^* > Q^*$ even though transfers are back to zero. This means the real interest rate $r_2^* > 1$ to induce the higher demand for real balances. The same argument applies to any $t \geq 2$. The result is a higher permanent real interest rate, $r_t > 1$, which induces a higher demand for real balances and lower young-consumption and capital investment than in the initial steady state. Maintaining inflation at target in response to a one-time fiscal expansion leads to a permanent recession.

Partial fiscal support

Now suppose $\theta_t < 1$, i.e., some interest expense is debt-financed. Then, given $r_1^* = 1$ and $z_2 = 0$, (36) and (37) imply $Q_2^* = \zeta + Q^*$, same as with full fiscal support. Hence, we get the same increase in the real interest rate, $r_2^* > 1$.

In the following period, we obtain $Q_3^* = (\zeta + Q^*)[1 + (1 - \theta_3)(r_2^* - 1)]$. Since $Q_3^* > \zeta + Q^* = Q_2^*$, we need $r_3^* > r_2^*$. That is, the real interest rate needs to increase even more to maintain inflation at target. The reason is that the unfunded interest expense implies an additional fiscal expansion, which needs to be sterilized. Specifically,

the real rate needs to increase to induce the higher demand for real balances necessary to maintain inflation at target.

The same argument can be applied to subsequent periods. That is, $r_t^* > r_{t-1}^*$ when $\theta_t < 1$ for $t \geq 2$. Clearly, without fiscal support the real rate consistent with inflation at target is on an ever-increasing path. At the same time, consumption and capital investment by young households decrease over time. To put an end to this dynamic, the interest expense needs to eventually be fully financed with taxes. That is, there needs to be a period $t = T$ such that $\theta_T = 1$. In this case, the real rate stabilizes at a level higher than had there been full fiscal support from the start. The permanent recession from that point on is correspondingly deeper.

5.4 Aggregate shocks

We now study the effects of aggregate shocks. Recall that there are three sources of aggregate uncertainty: the degree of patience of young households, α_t; earnings by type, $w_t(i)$; and the measure of young households with low earnings, σ_t. The following proposition establishes how aggregate shocks impact households' decisions. As in Proposition 1, we consider the impact of aggregate shocks on the consumption and savings decisions of the current generation of young households, which depend on whether households are debt-constrained or not.

Proposition 3. ***Impact of Aggregate Shocks on Young Households***

a. An increase in patience:

(i) for unconstrained young households, decreases consumption, has no effect on capital investment and increases holdings of real balances;

(ii) for constrained young households, decreases consumption and increases capital investment.

b. An increase in earnings:

(i) for unconstrained young households, has no effect on consumption and capital investment, and is fully saved in real balances;

(ii) for constrained young households, increases consumption and increases capital investment.

An increase in patience, what we may label a negative *demand* shock, decreases the consumption of all young households. The effect on desired savings depends on whether young households are debt-constrained or not. For unconstrained young households, optimal capital spending is independent of the demand shock. In this latter case, a negative demand shock simply increases holdings of real balances. For constrained households, greater patience implies a substitution from consumption to capital investment. On aggregate, consumption from young households decreases, while capital investment and holdings of real balances increase.

An increase in earnings, regardless of type, which we may label a positive *supply* shock, also has a disparate impact, depending on whether young households are debt-constrained or not. For unconstrained households, consumption and capital investment are at optimal, so higher earnings are fully saved in real balances. For constrained households, higher earnings lead to increases in consumption and capital investment. On aggregate, consumption, capital investment, and holdings of real balances all increase.

The last result has implications for the impact of the low-earnings shock, σ_t, which we may also label a *supply* shock. This shock changes the measure of young households that receive low earnings. Importantly, an increase in the measure of low earners implies a decrease in the demand for low balances. This has implications for inflation, which we investigate below.

The following proposition establishes the impact of aggregate shocks to patience and earnings on current and future inflation. Again, we focus on policy changes to an economy where all young households are unconstrained and there are no transfers, though more general results can be derived.

Proposition 4. ***Impact of Aggregate Shocks on Inflation***

Consider an equilibrium in which all young households are unconstrained and transfers are zero, i.e., $\lambda_t(i,j) = 0$ *for* $i = \{l,h\}$, $j = \{L,H\}$ *and* $z_t = 0$, *for all* $t \geq 1$.

a. *A one-time increase in patience decreases current inflation,* $d\Pi_t/d\alpha_t < 0$, *and increases inflation in the following period,* $d\Pi_{t+1}/d\alpha_t > 0$.

b. *A one-time increase in earnings decreases current inflation,* $d\Pi_t/dw_t < 0$, *and increases inflation in the following period,* $d\Pi_{t+1}/dw_t > 0$.

c. *A one-time increase in the measure of low-earning young households increases current inflation and decreases inflation in the following period, i.e.,* $d\Pi_t/d\sigma_t > 0$ *and* $d\Pi_{t+1}/d\sigma_t < 0$.

As we shall describe in the next section, we are going to characterize the COVID-19 shock as a combination of an increase in patience, a decrease in earnings for all types, and an increase in the measure of low-earning households. The demand shock is deflationary, while the supply shocks are both inflationary. The net effect of these shocks on inflation depends on their relative strength. We investigate this further below using a numerical version of our model calibrated to the U.S. economy.

6 Benchmark Economy

We study the U.S. economy over the five-year period 2020-2024. Period length is set to a year. We assume that the economy is on its steady-state growth path in 2019. All variables are detrended from their estimated steady-state growth paths. All impulse-response diagrams measure responses relative to trend.

6.1 Steady state calibration

We assume the following functional forms:

$$\begin{aligned} u(c) &= \frac{c^{1-\eta}-1}{1-\eta} \\ f(k) &= k^{\gamma} \end{aligned}$$

We set these parameters at standard values in the literature: $\eta = 2$ and $\gamma = 0.3$.

We set policy targets at $R^* = \Pi^* = r^* = 1$. That is, in steady state, the real rate is equal to the natural rate and there is no inflation.[5] We assume that all young

[5]Since the (net) nominal interest rate is zero in steady state, the share of interest expense financed with taxes, θ, is irrelevant for the calibration.

households receive the same endowment $w(h) = \omega$. That is, there are no households with low earnings ($\sigma = 0$) in steady state. We calibrate β_L so that impatient households optimally choose to hold zero real balances (that is, their debt constraints are satisfied with equality but do not bind). Thus, patient young households end up accumulating all the government debt. We set β_H so that government debt equals 25% of output, which matches holdings of the non-bank domestic sector in 2019.[6] We set the share of impatient households to one-half, which is similar to calibrations in DSGE models with hand-to-mouth agents. Table 1 summarizes the calibration.

Table 1: Benchmark Calibration

Parameter	Value	Definition
η	2.000	curvature of utility function
γ	0.300	curvature of production function
β_H	4.000	discounting by patient households
β_L	0.302	discounting by impatient households
ρ	0.500	share of impatient households
ω	2.000	endowment

Our calibration approach implies that in 2019 the benchmark economy is implementing the efficient allocation.

6.2 Fitting 2020-2024

We now describe how we fit the model to the data for 2020-24. The comparison between data and model is presented in Figure 2. We leave it to the next section to describe how the model projections beyond 2024 are formed.

First, we assume that $\theta_t = 0$ for 2020-24. That is, the interest expense of the debt is financed entirely with new debt over this time frame.

Second, we set σ_t so that the fraction of young impatient households subject to the low earnings shock matches the maximum drop in employment-to-population for 2020-21. In all other years, $\sigma_t = 0$. The implied values for σ_t are 0.191 and 0.067 for 2020 and 2021, respectively.

Third, we specify the following process for transfers: $z_t(\ell) = z_t(h) + UIP_t$. The series for UIP_t corresponds to unemployment insurance payments (including all the expansions and extensions provided by the CARES act and the American Rescue Plan), as a fraction of GDP, for 2020-21. Transfers to higher earners, $z_t(h)$ are calibrated so that the Primary Deficit / Debt implied by the model matches the data for 2020-21. For this target series, we use the consolidated primary deficit for the general government (i.e., federal, state, and local) from the flow of funds; the measure of debt includes Treasuries and municipal securities, net of foreign holdings.[7] Transfers are normalized to zero in all other years. The top-right panel of Figure 2 shows how we fit the Primary Deficit / Debt for 2020-21 and how it compares to the data in subsequent years.

[6] That is, we subtract the holdings of the Federal Reserve Banks, depository institutions, money market mutual funds and the foreign sector. The simple structure of our model (importantly, two-period lived agents and full capital depreciation) does not allow us to target total issuance of debt, which was about 80% of GDP in 2019. We instead target the holdings of a subset of the economy that resembles the households in our model.

[7] Looking at the consolidated government during this period is important, as transfers from the federal government to state governments were not immediately spent.

Fourth, we calibrate the earnings processes. We set $w_t(l)$ so that disposable income (earnings plus transfers minus taxes) is the same across young households in 2020-21. That is, we assume fiscal policy insures young households across *ex post* types.[8] Note that there are no young households type (ℓ, L) from 2022 onward. We set $w_t(h)$ to match real GDP per capita growth for 2020-24. The resulting aggregate earnings process, w_t is shown in the top-left panel of Figure 2. The top-middle panel shows that we match real GDP per capita growth exactly for all years. The model calibration implies that the economy has not quite recovered by 2024.

Fifth, the patience/demand shock α_t is set so that inflation in the model matches the annual PCE inflation rate for 2020-24. The top-left panel of Figure 2 shows the sequence of values for this shock necessary to match the data, shown in the bottom-middle panel.

Sixth, the parameter ϕ, which anchors inflation expectations around its target, is set to 0.702 so that inflation expectations in the model match the 1-year inflation expectations published by the Cleveland Fed at its peak in 2022. The fit is presented in the bottom-right panel of Figure 2.

Finally, the sequence of real interest rates implemented by monetary policy is set so that the nominal interest rate matches the minimum of the Effective Federal Funds Rate and the Wu-Xia estimates of the Shadow Federal Funds Rate.[9]

Figure 2: Benchmark dynamics relative to trend



The upper left panel in Figure 2 shows the estimated shock sequences for w_t and α_t. It is straightforward to interpret $\Delta w_t < 0$ as a negative supply shock. Since an increase in α_t induces consumers to delay spending, we can think of $\Delta \alpha_t > 0$ as a negative demand shock. Our calibrated model estimates that negative shocks to supply and demand were operational in 2020. Although the negative supply shock of 2020 reverses in 2021, its recovery is estimated to remain incomplete even into 2024. The negative demand shock of 2020 begins to reverse itself slowly in 2021 and 2022, and then more sharply in 2023. We take this estimated shock sequence as given in all the analysis that follows.

[8] As argued by Ganong, Noel and Vavra (2020) the median replacement ratio from unemployment insurance may have exceed 100% during the initial round of fiscal assistance in 2020.

[9] See `https://www.atlantafed.org/cqer/research/wu-xia-shadow-federal-funds-rate`.

The combined effects of the shocks and fiscal assistance imply that no households are debt-constrained throughout the simulation period. Recall that the steady state calibration implies that impatient young households optimally hold zero debt in 2019. Afterwards, the demand shock plus the fiscal assistance more than makes up for the impact of earnings loss, so that even impatient, low-earnings households are saving in real balances in 2020-21. From 2022 onward, even as extraordinary fiscal assistance is removed, the demand shock dominates the supply shock so that all impatient (and patient) households are saving.

By 2024, the (log) price level in the benchmark economy is about 11% higher than in an economy where the COVID-19 shocks and policy response did not occur.[10] As shown in the upper left panel of Figure 2 demand and supply shocks are still at play in 2024. In particular, negative demand shocks (i.e., $\alpha_t > 0$) explain why accumulated inflation has remained below the increase in government liabilities (about 16% in log differences). If these shocks were to eventually die out, then the total growth in the price level since 2019 would equal the growth in government debt.

6.3 Projections over 2025-29

In the exercises we conduct below, the model dynamics are not fully resolved by 2024. Thus, we need to make some assumptions on how the economy and policy are expected to evolve in subsequent years.

First, we assume that the current state of the economy is the best predictor of the future. Thus, we let aggregate shocks persist. That is, we assume that α_t and $w_t(h)$ remain at their 2024 values indefinitely.

Second, we need to specify the path for monetary policy. We take the Summary of Economic Projections released by the FOMC in December 2024. We use the projections for the federal funds rate for 2025-27 and the longer-run (2028 and beyond) and fit the path for the real rate that rationalizes this policy, given the path for inflation expectations. The procedure is similar to the calibrated path for 2020-24 but with the nominal rate implied by the Summary of Economic Projections rather than the actual rate.

By 2029 the price level in the benchmark model has converged at three decimal points. The total increase in the price level between 2019 and 2029 is 13.7%. This is our estimated impact of the COVID shocks and the policy response on inflation.

7 Counterfactual Exercises

7.1 No Fiscal Policy Response

To begin our analysis, we ask how the economy would have evolved had there been no extraordinary fiscal measures taken in 2020-21. In this experiment, we assume that monetary policy keeps the real rate of interest fixed at its 2019 level and continues to adjust the nominal policy rate according to the interest rule (10). The result is depicted in Figure 3.

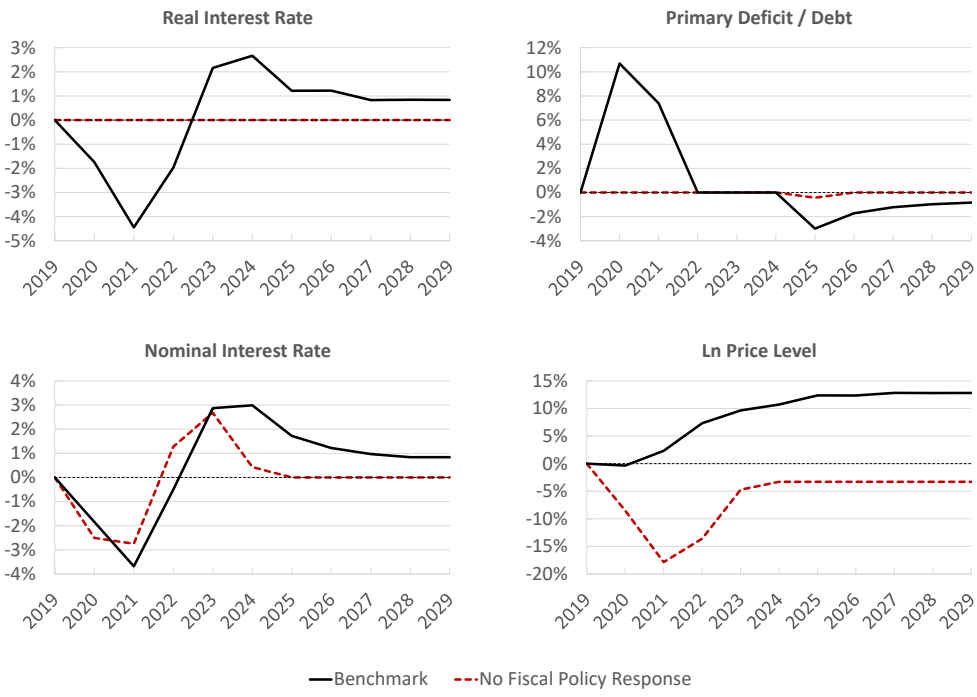
The bottom right panel of Figure 3 reveals that our calibrated model characterizes the COVID-19 pandemic as a deflationary event. The model predicts a deflation in 2020 and 2021, followed by an inflationary surge in 2022 and 2023, with the price level never

[10] We report the price level in logs and changes as log differences. These differences should be interpreted as deviations from trend.

fully recovering its pre-pandemic level (relative to trend). Evidence of this deflationary impulse can be seen in Figure 1. In particular, note the disinflation that occurred in 2020, despite very large fiscal transfers in that year.

While the absence of a fiscal response keeps the national debt in check, hidden in the aggregate dynamics described in Figure 3 is the hardship experienced by young households experiencing losses to their earnings capacity. In particular, in 2020-21 a fraction of impatient young households are hit by the low-earnings shock. Because these households have no accumulated savings to draw on, without fiscal assistance, their consumption and investment levels fall below what our planner above would dictate.

Figure 3: No Fiscal Policy Response



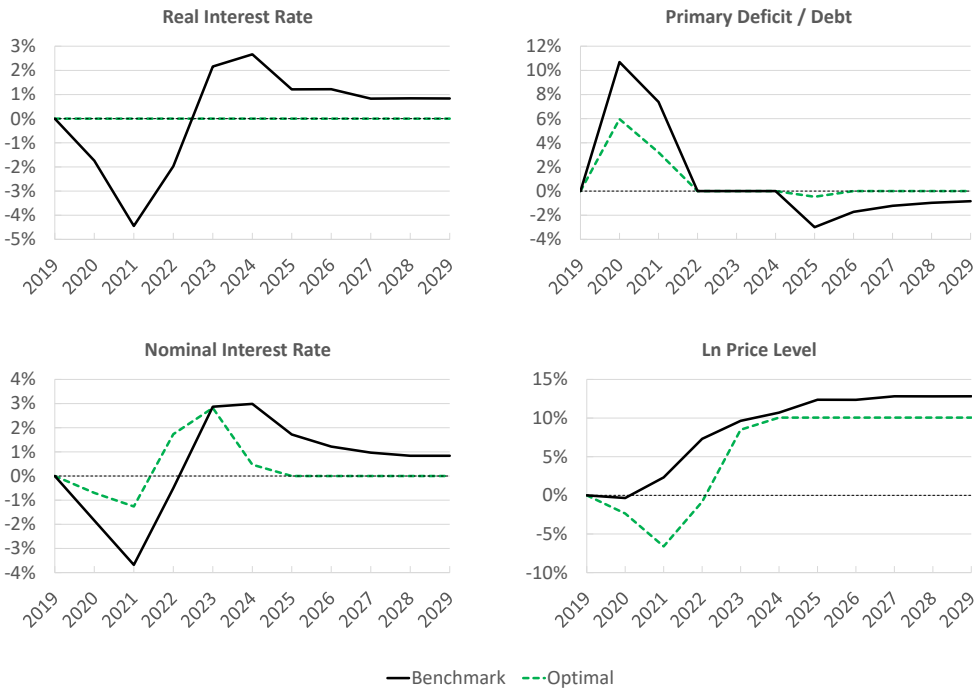
7.2 Optimal Policy

In this section, we describe a monetary-fiscal policy that implements the optimal allocation (4)–(6) given the shock realizations and projections described in Sections 6.2 and 6.3, and shown in Figure 2. As explained in Section 4.5, efficient implementation requires a monetary policy such that $r_t = 1$ and a fiscal policy such that $\lambda_t(i,j) = 0$ for $\{i = l, h\}$ and $j = \{L, H\}$. Monetary policy sets $r_t = 1$ for all t by adjusting the nominal rate one for one against inflation expectations, which evolve over time according to (32). Optimal fiscal policy involves transfers just large enough to relax debt constraints.[11] The results of this counterfactual exercise are reported in Figure 4.

The upper right panel of Figure 4 suggests that while fiscal programs such as the CARES Act of 2020 and the American Rescue Plan of 2021 were desirable, they were substantially larger than required. According to our model, the spending needed to

[11] As noted previously, larger-than-needed transfers also implement the optimal allocation, as they are saved, but result in higher inflation.

Figure 4: Benchmark vs. Optimal Policy



finance optimal insurance payments in both 2020 and 2021 should have generated primary deficits of roughly half the size of those observed. Consequently, the optimal policy involves a smaller expansion of the debt than in the benchmark economy (12% instead of 16%).

The bottom right panel of Figure 4 depicts the price level dynamic in the benchmark economy relative to the counterfactual experiment considered here. The price level under the optimal deficit policy increases by 10% (log-difference, relative to trend). This is very close to the increase of almost 11% in the benchmark economy by 2024, but somewhat smaller than the almost 13% increase generated in the benchmark economy by 2029. Thus, the model predicts that the overall increase in the cost of living would have been lower had fiscal policy been more restrained. The difference would be larger if the real interest rate in the benchmark economy were to return to its 2019 value instead of remaining elevated.

Note that the optimal price level dynamic in this case is very different than the benchmark. Figure 5 compares the inflation dynamics under the benchmark and optimal policies. In 2020, there is a modest deflation in the benchmark economy, followed by an inflation surge in 2021-22. In contrast, an optimal policy would have allowed the strong deflationary forces operating on the economy in those years (Re: top left panel of Figure 2) to manifest themselves as a significant deflation (again, relative to trend) in 2020 and 2021. One beneficial consequence of deflation in this model is that it increases the purchasing power of the 2020-21 money transfers delivered to distressed households.[12] However, the logic of our model requires the inflation tax to manifest itself at some

[12]In a model with sticky nominal wages, deflation would also increase the real wage, an effect that could be expected to discourage the recovery dynamic. Thus, a rationale for smoothing inflation could arise if nominal wages are slow to adjust.

point. Under an optimal policy, the inflation surge would have occurred in 2022-23 before rapidly tapering out in 2024 (with a lower overall increase in the price level).

Figure 5: Inflation Rate



It is conceivable that the optimal inflation rate dynamic would be smoother if we had modeled households as having nonlinear preferences and/or sticky nominal wages.[13] With quasilinear preferences, volatility in the realized rate of inflation does not affect *ex ante* welfare–it only affects the *ex post* welfare of old households. What matters for *ex ante* welfare here is how monetary policy responds to expected inflation. Expected inflation here (not depicted) is relatively smooth because expectations are adaptive and anchored around target. The optimal interest rate policy is correspondingly smooth relative to the benchmark; see the bottom left panel of Figure 4. Regarding the policy interest rate, the optimal policy involves more modest loosening in 2020-21 and less aggressive tightening in 2022-23. Under an optimal policy, the policy interest rate should have returned close to its pre-pandemic level by 2024. Because an optimal fiscal policy in our model relaxes all credit constraints, monetary policy is free to target the "natural" real rate of interest. Our model suggests that the real rate of interest was too low (monetary policy too loose) during the period 2020-22 and too high (tight) during 2023-24.

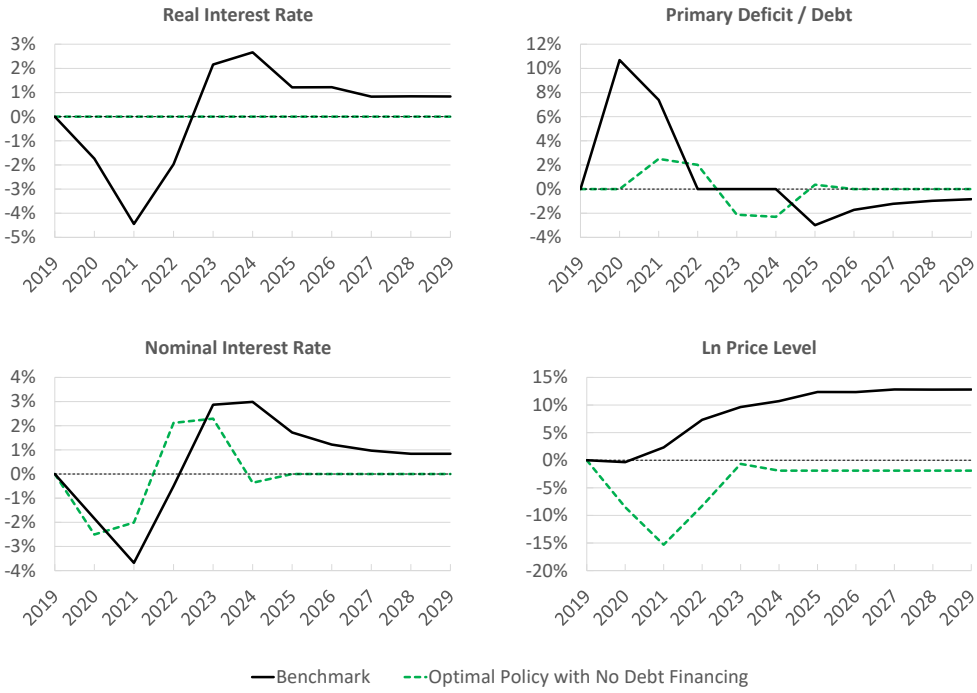
The experiment considered above assumes that the extraordinary spending associated with the COVID-19 pandemic is deficit-financed. It is of some interest to consider the case in which the spending was instead financed through a non-distortionary tax. Figure 6 depicts the predicted dynamics relative to the benchmark.

The top right panel of Figure 6 shows a moderate dynamic (relative to trend) in the primary deficit. This is owing to our assumption that in the periods following the CARES/ARP spending, the interest expense of the debt is financed through adjustments in the primary surplus. The bottom right panel displays the price level dynamic. A tax-financed spending program is predicted to be deflationary in 2020 and inflationary in 2021, with the inflation rebound largely sending the price level near (but still below) its steady-state path. Note that the price level never fully recovers because we assume that the negative demand shock persists into the indefinite future.

The bottom left panel of Figure 6 shows that monetary policy under a tax-financed emergency spending program would have optimally followed a path similar to the case where spending was deficit-financed. That is, while the price level behaves very differently under these two methods of finance, the inflation dynamic is similar. This implies

[13]Doing so would not have changed the conclusion pertaining to the overall amount of inflation experienced.

Figure 6: Benchmark vs. Optimal Policy with No Debt Financing



a similar dynamic for expected inflation and, hence, for the optimal monetary policy interest rate.

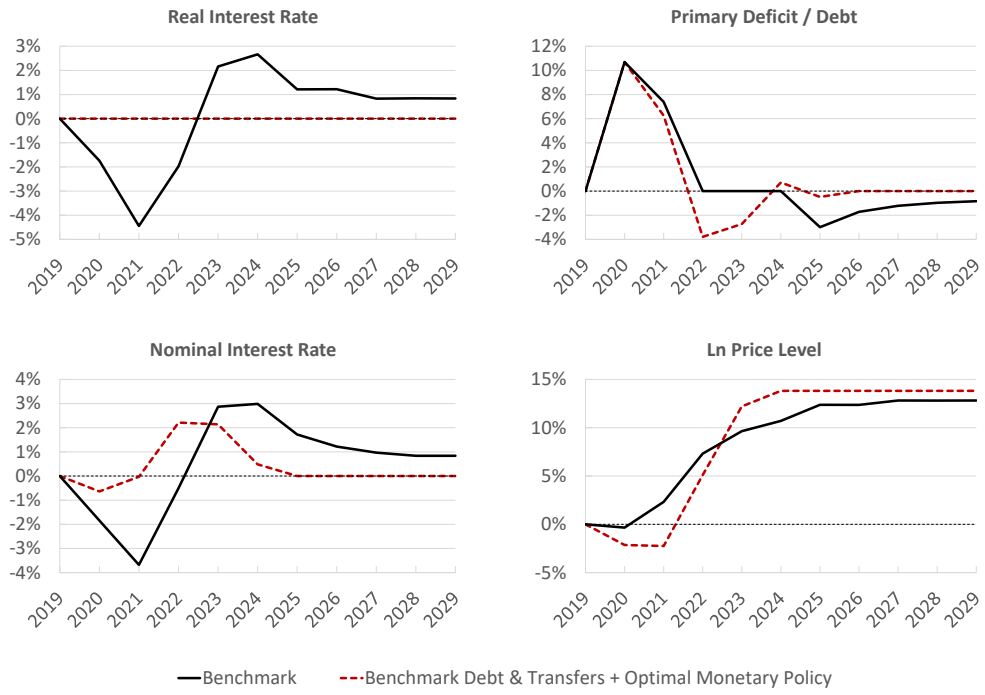
7.3 Optimal Monetary Policy Given Fiscal Policy

The Federal Open Market Committee of the Federal Reserve views fiscal policy as beyond its control when formulating its interest rate policy. Our analysis above suggests that the fiscal transfers and primary deficits during 2021-22 were larger than necessary (at least in hindsight). In other words, the inflationary impulse of fiscal policy was greater than it should have been. How should monetary policy have responded to this larger than necessary inflationary impulse?

Because the smaller fiscal transfer program described in the previous section is sufficient to relax credit constraints, the larger program considered here achieves the same result—albeit, through overkill. The monetary authority in our model is therefore left to target the natural rate of interest, which we continue to assume remained constant throughout the episode. The resulting dynamics are displayed in Figure 7

To achieve the monetary policy goal of targeting the expected natural rate of interest, our model suggests that the policy rate should have been cut only modestly in 2020 and returned to its pre-pandemic level by 2021. The Fed should have raised its policy rate by 200bp in 2022, keeping it at this level throughout 2023, before lowering it back near its pre-pandemic level in 2024; see bottom left panel of Figure 7. This relatively modest undulation in the policy rate path essentially follows the path of inflation expectations. It is also a policy path that is consistent with the Fed critics arguing for an earlier and more aggressive tightening of monetary policy.

Figure 7: Optimal Monetary Policy Given Fiscal Policy



While our model agrees with Fed critics on monetary policy, it disagrees over the effect this counterfactual policy would have had. The bottom right panel of Figure 7 shows that given fiscal policy, an optimal monetary policy would have made very little difference in the total amount of inflation experienced in the economy.[14] Without fiscal support, interest rate policy in our model can only determine the timing of inflation. As in the earlier experiment (see Figure 4), the optimal policy simply backloads the inflation surge without eliminating it. According to our model, the Fed should have allowed disinflation to persist throughout 2020-21. Doing so would have implied an even stronger inflation surge in 2022. This is the inflation tax that is necessary to finance the given unfunded fiscal expenditures.

7.4 Inflation Targeting

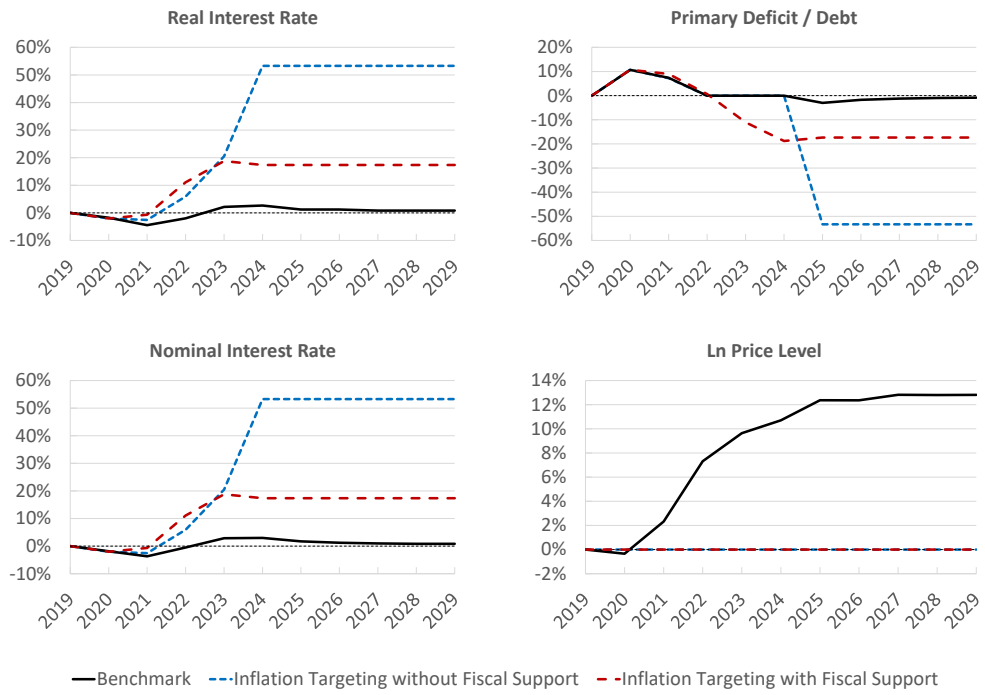
Our economic environment is one in which the long-term inflation target is ultimately determined by the fiscal authority.[15] However, because the monetary authority can influence the real interest rate in the short term, it also has the power to determine the path of the price level in the short term. It is worth stressing that in this model, the real interest level influences the price level, not the inflation rate, as shown by condition (20). The real interest rate affects the demand for nominal government liabilities, which given nominal supply, determines the price level. It is the *path* of the real interest rate that influences the inflation rate. In Section 5.3 we characterized the real interest rate policy necessary for maintaining inflation at target in response to a one-time increase in transfers and how this policy depended on fiscal support.

[14] The reader will notice that the price level is lower in the benchmark economy. This is because the real interest rate is higher, which serves to increase the level demand for real money balances.

[15] In most economic models, fiscal support for the assumed inflation target is implicit.

In the following experiment, we provide a counterfactual experiment in which monetary policy uses all of its power to keep inflation on target assuming the observed fiscal policy over 2020-24 and assuming full fiscal support for the inflation-targeting policy beyond 2024. As in the benchmark economy, we set $\theta_t = 0$ for 2020-24 and $\theta_t = 1$ from 2025 onward. The dynamics from this counterfactual experiment are recorded in the square-dotted blue lines in Figure 8.

Figure 8: Inflation Targeting conditional on Fiscal Support for 2020-24



As Figure 8 reveals, strict inflation targeting appears to be feasible for a central bank, but only for a limited period of time. In Figure 8, the real interest rises to astronomical levels and remains there only due to the assumed primary surplus that becomes operational in 2025. Without this fiscal support, maintaining inflation at target would require an ever-increasing real interest rate. Eventually, either fiscal policy provides support by taxing the interest expense or monetary policy abandons the inflation target, in which case the real interest rate would collapse back to zero and there would be a jump in the price level proportional to the accumulated increase in debt. The sharp and persistent increase in the real interest rate would have sent the economy into a sustained recession.[16]

Figure 8 also presents an alternative counterfactual scenario, the red dashed lines, in which the fiscal authority supports monetary policy by financing the entire expense of the debt with taxes, i.e., setting $\theta_t = 1$ throughout. The qualitative dynamics are similar as in the case when such fiscal support comes up in 2025, except that fiscal support materializes sooner. However, the quantitative effects can be significant. Now, the fiscal authority finances the budgetary impact of monetary policy and so, the required real interest rate that implements the inflation target has a significantly lower terminal point

[16] In the model, this occurs through a contraction in capital investment. But in richer models and in reality, this would occur through a variety of other channels.

when compared to the previous counterfactual. The economy still suffers a permanent recession, albeit a milder one.

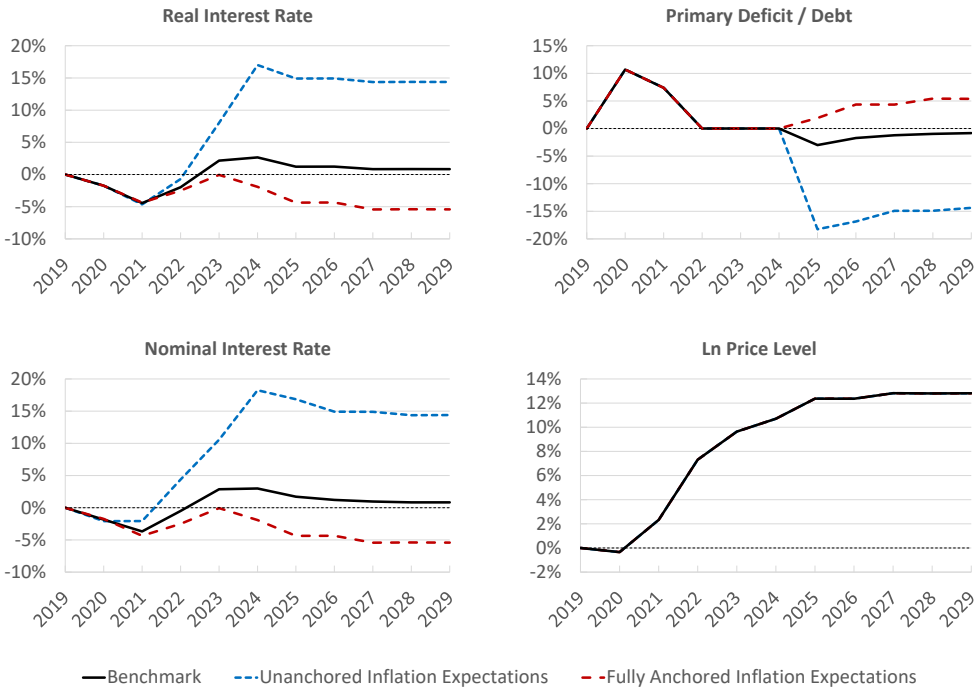
7.5 The role of anchored inflation expectations

Our benchmark calibration assumes some degree of anchoring in inflation expectations that rationalizes the fact that expectations rose far less than observed inflation. As mentioned above, an important part of the official narrative is that ensuring inflation expectations remained well-anchored was critical to achieving a "soft landing." We evaluate this assertion by varying the degree to which inflation expectations are anchored.

First, suppose inflation expectations are unanchored in the sense that $\phi = 0$. In this case, inflation expectations are equal to observed inflation. Second, suppose that inflation expectations are fully anchored in the sense that $\phi = 1$. In this case, inflation expectations are always equal to the target.

Figure 9 shows how monetary policy would have looked like if it was designed to achieve the same inflation dynamic as in the benchmark, when facing the observed fiscal policy but either without an anchor on inflation expectations or with fully anchored inflation expectations. As with the benchmark case, in both counterfactual exercises we assume full fiscal support, $\theta_t = 1$, from 2025 onward.

Figure 9: Anchored vs. Unanchored Inflation Expectations



For the case with unanchored inflation expectations, Figure 9 shows that the real and nominal interest rates would have had to increase more than if inflation expectations had not been anchored. In addition, the lack of anchor also implies that the terminal real rate is higher as well, necessitating larger fiscal support and implying a higher adverse impact on economic activity. In contrast, if inflation expectations were fully anchored, then the real and nominal interest rates would have kept below the benchmark, though following

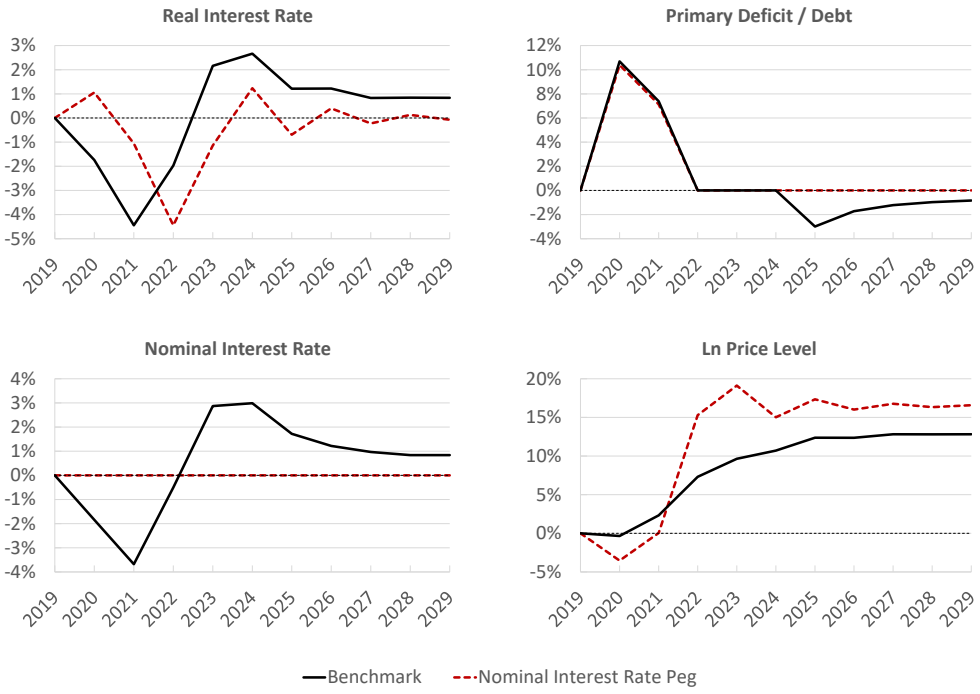
a similar dynamic. In this case, lower interest rates have a benign effect on the primary deficit, as the expansion of the debt due to the interest expense is correspondingly smaller than in the benchmark. Overall, our model is compatible with the narrative that well-anchored inflation expectations were critical in achieving the disinflation at a low economic cost, for a given desired inflation path.

There are two important caveats to the narrative. First, the anchor is not critical for the return of actual inflation to the target; this is achieved via the appropriate fiscal support. Second, with unanchored inflation expectations, the Fed could have instead implemented the same real interest rate path (and thus, kept the economic impact the same) and let inflation rise higher than in the benchmark.

7.6 Transitory Inflation With a Nominal Interest Rate Peg

In his speech at Jackson Hole, Fed Governor Jerome Powell took credit for the rapid disinflation that occurred soon after inflation peaked in the summer of 2022 (Powell, 2024). To evaluate this claim, we compute the model dynamics assuming that the Fed keeps its policy rate at its 2019 level throughout the entire episode. The results are reported in Figure 10.

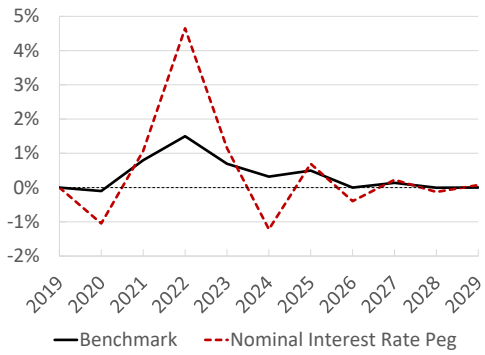
Figure 10: Nominal Interest Rate Peg



The bottom right panel of Figure 10 supports Chair Powell's claim in one sense, but not in another. Our model supports the notion that active Fed policy mitigated the inflation surge relative to what would have transpired had the Fed kept its policy rate unchanged. In fact, the overall increase in the price level is lower than it otherwise would have been. The reason for this latter result has to do with the fact that the Fed is keeping the real rate of interest elevated relative to its pre-pandemic level (and relative to what is optimal in the model). However, our model rejects the claim that an

aggressive Fed policy was necessary to anchor inflation expectations; e.g., see Bundick, Smith and der Meer (2024). Figure 11 reports the dynamics of expected inflation under the two monetary policies considered here. Aggressive monetary policy did serve to smooth expectations of inflation, but was not necessary to anchor these expectations.

Figure 11: Expected Inflation Rate



8 Conclusions

The COVID-19 pandemic disrupted household earnings in a highly uneven manner and induced significant shifts in economic behavior, including a widespread inclination to defer consumption. Our model suggests that the fiscal response in the United States was broadly appropriate, though arguably excessive in scale. It was almost certainly preferable to policy inaction. That said, a similarly effective income support program—if financed through a temporary surtax—could have delivered comparable welfare benefits while exerting less upward pressure on inflation.

Given the observed fiscal response and the nature of the pandemic shock, the Federal Reserve likely erred in lowering its policy rate as much as it did and in delaying the subsequent rate hikes. However, even under a more responsive policy stance, the inflation surge would likely have been postponed rather than avoided. Preventing the inflation entirely would have required a persistently rising real interest rate path—an approach that would have risked undermining the economic recovery. In short, the Fed could not have offset the COVID-19-induced price level shock through interest rate policy alone. While the subsequent tightening helped smooth the inflation trajectory and reinforce expectations, such aggressive action was not strictly necessary to maintain credibility.

This interpretation stands in contrast to many prevailing narratives. While our conclusions are based on a relatively simple model, we believe the qualitative insights are robust to a range of model extensions. The policy implications are significant: in response to large exogenous shocks—such as wars or pandemics—monetary policy should, at least temporarily, deprioritize short-term inflation stabilization. Simultaneously, it is imperative that fiscal policy remain credibly anchored. Sustaining the Federal Reserve's long-run inflation target ultimately requires consistent fiscal support.

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A Efficient allocation

Household type $j = \{L, H\}$ has preferences

$$U_t(j) = E_t[(1-\alpha_t)(1/\beta_j)u(c_t^y) + c_{t+1}^o]$$

The social welfare function is $W = E_1 \sum_{t=0}^{\infty} \delta^t \{\rho U_t(L) + (1-\rho)U_t(H)\}$, where $U_0(j) = c_1^o(j)$. That is,

$$W = E_1 \sum_{t=1}^{\infty} \delta^t \Big\{ \rho[(1-\alpha_t)(1/\beta_L)u(c_t^y(L)) + (1/\delta)c_t^o(L)] \\ + (1-\rho)[(1-\alpha_t)(1/\beta_H)u(c_t^y(H)) + (1/\delta)c_t^o(H)] \Big\}$$

The resource constraint is given by,

$$w_t + f(k_{t-1}) - \rho[c_t^y(L) + c_t^o(L)] - (1-\rho)[c_t^y(H) + c_t^o(H)] - k_t \geq 0$$

for all $t = 1, \ldots, \infty$. Initial capital, k_0 is given.

With Lagrange multiplier $\delta^t \lambda_t$ on the resource constraints, the first-order conditions of the planner's problem are

$$\begin{aligned}
\delta^t \rho(1-\alpha_t)(1/\beta_L)u'(c_t^y(L)) - \delta^t \rho \lambda_t &= 0 \\
\delta^t (1-\rho)(1-\alpha_t)(1/\beta_H)u'(c_t^y(H)) - \delta^t (1-\rho)\lambda_t &= 0 \\
\delta^{t-1}\rho - \delta^t \rho \lambda_t &= 0 \\
\delta^{t-1}(1-\rho) - \delta^t (1-\rho)\lambda_t &= 0 \\
-\delta^t \lambda_t + \delta^{t+1} f'(k_t) E_t \lambda_{t+1} &= 0
\end{aligned}$$

for all $t = 1, \ldots, \infty$. The system simplifies to

$$\begin{aligned}
(1-\alpha_t)u'(c_t^y(j)) &= \beta_j \lambda_t \\
1 &= \delta \lambda_t \\
\lambda_t &= \delta f'(k_t) E_t \lambda_{t+1}
\end{aligned}$$

for $j = \{L, H\}$ and all $t = 1, \ldots, \infty$. Hence, $\lambda_t = 1/\delta$ and so,

$$\begin{aligned}
(1-\alpha_t)u'(c_t^y(j)) &= \beta_j/\delta \\
f'(k_t) &= 1/\delta
\end{aligned}$$

When $\delta = 1$ we obtain (4)–(6).

Note that the planner's problem does not pin-down $c_t^o(L)$ and $c_t^o(H)$ but rather $c_t^o \equiv \rho c_t^o(L) + (1-\rho)c_t^o(H)$. This follows from quasi-linearity: as shown in the equations above, the FOCs wrt $c_t^o(j)$ are the same for both types, so we lose one equation. The efficient allocation is silent about how consumption is allocated among the old. Hence, it is sufficient to show that an equilibrium implements the allocation $(\hat{c}_t^y(L), \hat{c}_t^y(H), \hat{k}_t)$ to show that it is efficient.

B Proofs

Proof of Proposition 1.

a. (i) Suppose $\lambda_t(i,j) = 0$. Then, (35) implies

$$f''(k_t(i,j))\frac{dk_t(i,j)}{dz_t(i)} = 0 \tag{B.1}$$

and so, $\frac{dk_t(i,j)}{dz_t(i)} = 0$. From (16) we obtain

$$(1-\alpha_t)u''(c_t^y(i,j))\frac{dc_t^y(i,j)}{dz_t(i)} = \beta_j f''(k_t(i,j))\frac{dk_t(i,j)}{dz_t(i)} \tag{B.2}$$

Combining (B.1) and (B.2) we get $\frac{c_t^y(i,j)}{dz_t(i)} = 0$. From (18) we obtain

$$\frac{dc_t^y(i,j)}{dz_t(i)} = -\left[\frac{dq_t(i,j)}{dz_t(i)} + \frac{dk_t(i,j)}{dz_t(i)}\right] + 1 \tag{B.3}$$

Given $\frac{c_t^y(i,j)}{dz_t(i)} = \frac{k_t(i,j)}{dz_t(i)} = 0$, (B.3) implies $\frac{dq_t(i,j)}{dr_t} = 1$.

(ii) Suppose $\lambda_t(i,j) > 0$. Then $q_t(i,j) = 0$ and so, $\frac{dq_t(i,j)}{dr_t} = 0$. Hence, (B.3) implies

$$\frac{dc_t^y(i,j)}{dz_t(i)} + \frac{dk_t(i,j)}{dz_t(i)} = 1 \tag{B.4}$$

and from (B.2) we obtain

$$\left[(1-\alpha_t)u''(c_t^y(i,j)) + \beta_j f''(k_t(i,j))\right]\frac{dc_t^y(i,j)}{dz_t(i)} = \beta_j f''(k_t(i,j)) \tag{B.5}$$

Hence, $\frac{dc_t^y(i,j)}{dz_t(i)} > 0$. Similarly, combining (B.4) and (B.5) implies

$$(1-\alpha_t)u''(c_t^y(i,j)) = \left[\beta_j f''(k_t(i,j)) + (1-\alpha_t)u''(c_t^y(i,j))\right]\frac{dk_t(i,j)}{dz_t(i)} \tag{B.6}$$

and so, $\frac{dk_t(i,j)}{dz_t(i)} > 0$.

b. (i) Suppose $\lambda_t(i,j) = 0$. Then, (35) implies

$$f''(k_t(i,j))\frac{dk_t(i,j)}{dr_t} = 1 \tag{B.7}$$

and so, $\frac{dk_t(i,j)}{dr_t} = \frac{1}{f''(k_t(i,j))} < 0$. From (16) we obtain

$$(1-\alpha_t)u''(c_t^y(i,j))\frac{dc_t^y(i,j)}{dr_t} = \beta_j f''(k_t(i,j))\frac{dk_t(i,j)}{dr_t} \tag{B.8}$$

Combining (B.7) and (B.8) we get $\frac{c_t^y(i,j)}{dr_t} = \frac{\beta_j}{(1-\alpha_t)u''(c_t^y(i,j))} < 0$. From (18) we obtain

$$\frac{dc_t^y(i,j)}{dr_t} = -\left[\frac{dq_t(i,j)}{dr_t} + \frac{dk_t(i,j)}{dr_t}\right] \tag{B.9}$$

and hence, $\frac{dq_t(i,j)}{dr_t} = -\left[\frac{\beta_j}{(1-\alpha_t)u''(c_t^y(i,j))} + \frac{1}{f''(k_t(i,j))}\right] > 0$.

(ii) Suppose $\lambda_t(i,j) > 0$. Then $q_t(i,j) = 0$ and so, $\frac{dq_t(i,j)}{dr_t} = 0$. Hence, (B.9) implies

$$\frac{dc_t^y(i,j)}{dr_t} = -\frac{dk_t(i,j)}{dr_t} \tag{B.10}$$

and so (B.8) implies

$$(1-\alpha_t)u''(c_t^y(i,j))\frac{dc_t^y(i,j)}{dr_t} = -\beta_j f''(k_t(i,j))\frac{dc_t^y(i,j)}{dr_t} \tag{B.11}$$

which can only be satisfied if $\frac{dc_t^y(i,j)}{dr_t} = 0$. Thus, $\frac{dc_t^y(i,j)}{dr_t} = \frac{dk_t(i,j)}{dr_t} = 0$. □

Proof of Proposition 2.

a. From (25) we obtain

$$\frac{d\Pi_t}{dz_t} = -\left(\frac{\Pi_t}{Q_t - z_t}\right)\left(\frac{dQ_t}{dz_t} - 1\right) \tag{B.12}$$

From Proposition 1, $\frac{dq_t(i,j)}{dz_t(i)} = 1$ if $\lambda_t(i,j) = 0$. Hence, $\frac{dQ_t}{dz_t} = 1$ and so, $\frac{d\Pi_t}{dz_t} = 0$.

Updating (25) one period, imposing $z_{t+1} = 0$ and combining with (33) implies

$$\Pi_{t+1} = \frac{Q_t[1 + (1-\theta_{t+1})(r_t\Pi_t^{1-\phi} - 1)]}{Q_{t+1}} \tag{B.13}$$

The impact of a one-time increase in transfers has no impact on Q_{t+1}. Then, given $\frac{dQ_t}{dz_t} = 1$ and $\frac{d\Pi_t}{dz_t} = 0$ we obtain

$$\frac{d\Pi_{t+1}}{dz_t} = \frac{1 + (1-\theta_{t+1})(r_t\Pi_t^{1-\phi} - 1)}{Q_{t+1}} \tag{B.14}$$

and so, $\frac{d\Pi_{t+1}}{dz_t} > 0$.

b. From (25) we obtain

$$\frac{d\Pi_t}{dr_t} = -\frac{\Pi_t}{Q_t}\frac{dQ_t}{dr_t} \tag{B.15}$$

From Proposition 1, $\frac{dq_t(i,j)}{dr_t} > 0$ if $\lambda_t(i,j) = 0$. Hence, $\frac{dQ_t}{dr_t} > 0$ and so, $\frac{d\Pi_t}{dr_t} < 0$.

The impact of a one-time increase in r_t has no impact on Q_{t+1}. Then, from (B.13) and (B.15) we obtain

$$\frac{d\Pi_{t+1}}{dr_t} = \frac{1}{Q_{t+1}}\left\{\left[\theta_{t+1} + (1-\theta_{t+1})\phi r_t\Pi_t^{1-\phi}\right]\frac{dQ_t}{dr_t} + Q_t(1-\theta_{t+1})\Pi_t^{1-\phi}\right\} \tag{B.16}$$

Given $\frac{dQ_t}{dr_t} > 0$, (B.16) implies that $\frac{d\Pi_{t+1}}{dr_t} > 0$. □

Proof of Proposition 3.

a. (i) Suppose $\lambda_t(i,j) = 0$. Then, (35) implies

$$f''(k_t(i,j))\frac{dk_t(i,j)}{d\alpha_t} = 0 \tag{B.17}$$

and so, $\frac{dk_t(i,j)}{d\alpha_t} = 0$. Given this result, from (16) we obtain

$$(1-\alpha_t)u''(c_t^y(i,j))\frac{dc_t^y(i,j)}{d\alpha_t} = u'(c_t^y(i,j)) \tag{B.18}$$

Hence, $\frac{dc_t^y(i,j)}{d\alpha_t} = \frac{u'(c_t^y(i,j))}{(1-\alpha_t)u''(c_t^y(i,j))} < 0$. From (18) we obtain

$$\frac{dc_t^y(i,j)}{d\alpha_t} = -\frac{dq_t(i,j)}{d\alpha_t} \tag{B.19}$$

and so, $\frac{dq_t(i,j)}{d\alpha_t} > 0$.

(ii) Suppose $\lambda_t(i,j) > 0$. Then $q_t(i,j) = 0$ and so, $\frac{dq_t(i,j)}{d\alpha_t} = 0$. From (16) we obtain

$$(1-\alpha_t)u''(c_t^y(i,j))\frac{dc_t^y(i,j)}{d\alpha_t} - u'(c_t^y(i,j)) = \beta_j f''(k_t(i,j)\frac{dk_t(i,j)}{d\alpha_t} \tag{B.20}$$

and, given $\frac{dq_t(i,j)}{d\alpha_t} = 0$, (18) implies

$$\frac{dc_t^y(i,j)}{d\alpha_t} = -\frac{dk_t(i,j)}{d\alpha_t} \tag{B.21}$$

Combining (B.20) and (B.21) implies

$$[(1-\alpha_t)u''(c_t^y(i,j)) + \beta_j f''(k_t(i,j)]\frac{dc_t^y(i,j)}{d\alpha_t} = u'(c_t^y(i,j)) \tag{B.22}$$

and so, $\frac{dc_t^y(i,j)}{d\alpha_t} < 0$ and $\frac{dk_t(i,j)}{d\alpha_t} > 0$.

b. (i) Suppose $\lambda_t(i,j) = 0$. Then, (35) implies

$$f''(k_t(i,j))\frac{dk_t(i,j)}{dw_t(i)} = 0 \tag{B.23}$$

and so, $\frac{dk_t(i,j)}{dw_t(i)} = 0$. Given this result, from (16) we obtain

$$(1-\alpha_t)u''(c_t^y(i,j))\frac{dc_t^y(i,j)}{dw_t(i)} = 0 \tag{B.24}$$

Hence, $\frac{dc_t^y(i,j)}{dw_t(i)} = 0$. Then, (18) implies $\frac{dq_t(i,j)}{d\alpha_t} = 1$.

(ii) Suppose $\lambda_t(i,j) > 0$. Then $q_t(i,j) = 0$ and so, $\frac{dq_t(i,j)}{d\alpha_t} = 0$. From (16) we obtain

$$(1-\alpha_t)u''(c_t^y(i,j))\frac{dc_t^y(i,j)}{dw_t(i)} = \beta_j f''(k_t(i,j)\frac{dk_t(i,j)}{dw_t(i)} \tag{B.25}$$

and, given $\frac{dq_t(i,j)}{d\alpha_t} = 0$, (18) implies

$$\frac{dc_t^y(i,j)}{dw_t(i)} = 1 - \frac{dk_t(i,j)}{dw_t(i)} \tag{B.26}$$

Combining (B.25) and (B.26) implies

$$[(1-\alpha_t)u''(c_t^y(i,j)) + \beta_j f''(k_t(i,j)]\frac{dc_t^y(i,j)}{d\alpha_t} = \beta_j f''(k_t(i,j) \tag{B.27}$$

and so, $\frac{dc_t^y(i,j)}{d\alpha_t} > 0$. Similarly,

$$(1-\alpha_t)u''(c_t^y(i,j)) = [(1-\alpha_t)u''(c_t^y(i,j)) + \beta_j f''(k_t(i,j)]\frac{dk_t(i,j)}{d\alpha_t} \tag{B.28}$$

and so, $\frac{dk_t(i,j)}{d\alpha_t} > 0$. □

Proof of Proposition 4.

a. From (25) we obtain

$$\frac{d\Pi_t}{d\alpha_t} = -\frac{\Pi_t}{Q_t}\frac{dQ_t}{d\alpha_t} \tag{B.29}$$

From Proposition 3, $\frac{dq_t(i,j)}{d\alpha_t} > 0$ if $\lambda_t(i,j) = 0$. Hence, $\frac{dQ_t}{d\alpha_t} > 0$ and so, $\frac{d\Pi_t}{d\alpha_t} < 0$.

From (B.13) and (B.29) we obtain

$$\frac{d\Pi_{t+1}}{d\alpha_t} = \frac{1}{Q_{t+1}}\left[\theta_{t+1} + (1-\theta_{t+1})\phi r_t \Pi_t^{1-\phi}\right]\frac{dQ_t}{d\alpha_t} \tag{B.30}$$

Given $\frac{dQ_t}{d\alpha_t} > 0$, $\frac{d\Pi_{t+1}}{d\alpha_t} > 0$.

b. From (25) we obtain

$$\frac{d\Pi_t}{dw_t} = -\frac{\Pi_t}{Q_t}\frac{dQ_t}{dw_t} \tag{B.31}$$

From Proposition 3 we have $\frac{dq(i,j)}{dw(i)} = 1$ when $\lambda(i,j) = 0$. Hence, $\frac{dQ_t}{dw_t} > 0$ and so, $\frac{d\Pi_t}{dw_t} < 0$.

From (B.13) and (B.31) we obtain

$$\frac{d\Pi_{t+1}}{d\alpha_t} = \frac{1}{Q_{t+1}}\left[\theta_{t+1} + (1-\theta_{t+1})\phi r_t \Pi_t^{1-\phi}\right]\frac{dQ_t}{dw_t} \tag{B.32}$$

Given $\frac{dQ_t}{dw_t} > 0$, $\frac{d\Pi_{t+1}}{dw_t} > 0$.

c. From (21),

$$\frac{dQ_t}{d\sigma_t} = \rho[q_t(l,L) - q_t(h,L)] \tag{B.33}$$

From Proposition 3 we have $\frac{dq(i,j)}{dw(i)} = 1$. Hence, given $w(l) < w(h)$ we get $q_t(l,L) < q_t(h,L)$. Therefore, (B.33) implies $\frac{dQ_t}{d\sigma_t} < 0$.

From (25) and (B.33) we obtain

$$\frac{d\Pi_t}{d\sigma_t} = -\frac{\Pi_t \rho[q_t(l,L) - q_t(h,L)]}{Q_t} \tag{B.34}$$

which implies $\frac{d\Pi_t}{d\sigma_t} > 0$.

From (B.13), (B.33) and (B.34) we obtain

$$\frac{d\Pi_{t+1}}{d\sigma_t} = \frac{\rho[q_t(l,L) - q_t(h,L)]}{Q_{t+1}} \left[\theta_{t+1} + (1-\theta_{t+1})\phi r_t \Pi_t^{1-\phi}\right] \tag{B.35}$$

and so, $\frac{d\Pi_{t+1}}{d\sigma_t} < 0$. □