The St. Louis Fed DSGE Model*

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Abstract

This document contains a technical description of the dynamic stochastic general equilibrium (DSGE) model developed and maintained by the Research Division of the St. Louis Fed as one of its tools for forecasting and policy analysis. The St. Louis Fed model departs from an otherwise standard medium-scale New Keynesian DSGE model along two main dimensions: first, it allows for household heterogeneity, in the form of workers and capitalists, who have different marginal propensities to consume (MPC). Second, it explicitly models a fiscal sector endowed with multiple spending and revenue instruments, such as social transfers and distortionary income taxes. Both of these features make the model well-suited for the analysis of fiscal policy counterfactuals and monetary-fiscal interactions. We describe how the model is estimated using historical data for the US economy and how the COVID-19 pandemic is accounted for. Some examples of model output are presented and discussed.

Keywords: DSGE model; policy analysis; New Keynesian model; TANK model; Bayesian estimation; fiscal policy
JEL Classification: E1, E2, E3, E4, E5

1 Introduction

In this document, we describe a dynamic stochastic general equilibrium (DSGE) model that can be used for policy analysis and forecasting. The model takes mostly standard ingredients found in medium-scale DSGE models (Christiano et al., 2005; Smets and Wouters, 2007) and extends the standard model along a few dimensions that are not typically considered in models used at central banks. In particular, our model contains both household heterogeneity and a more detailed description of fiscal policy.

The base of the model is similar to the current models adopted by different Federal Reserve Banks across the Federal Reserve System: New York (Cocci et al., 2013; Del Negro et al., 2017),

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Philadelphia (Arias et al., 2019), Chicago (Campbell et al., 2023), or Cleveland (Gelain and Lopez, 2023). Each of these models puts more emphasis on certain aspects of modeling and/or measurement: financial frictions, frictional labor markets, etc. Our modeling framework, instead, takes a more conventional approach to these features, but allows us to directly analyze the macroeconomic effects of different types of fiscal policy on the economy and on fiscal variables such as government debt. Features such as an explicit financial intermediation sector or search-and-matching labor markets are not explicitly considered but can easily be added to the current framework.

Following standard practice, we externally calibrate some parameters and estimate the rest using Bayesian methods. The estimation period runs from 1959Q1 to the most recent available data, 2025Q2 in this version of the draft. The estimation sample includes the highly abnormal COVID-19 period, which featured extremely large movements in certain macroeconomic time series that are used as observables, such as real GDP or private consumption expenditures growth. We account for the unusual effects of the COVID-19 pandemic by adding one-time i.i.d. components with a larger standard deviation to some of the exogenous variables (Ferroni et al., 2022; Cocci et al., 2013). This accounts for extraordinary movements in aggregate demand, labor supply and fiscal policy, among other sources of impulses, that were large but short-lived.

Key differences relative to other models. There are two specific departures from other models. First, we allow for household heterogeneity in the form of two agents with heterogeneous marginal propensities to consume. In order to leverage the methodology and toolkits that have been developed to solve and estimate models of this kind, we assume a limited form heterogeneity: instead of a representative Ricardian agent, we assume that there are two types of agents, capitalists and workers, following the recent work of Cantore and Freund (2021). Capitalists do not work, are the residual claimants to all financial assets in the economy, and otherwise behave in a manner that is similar to that of the representative agent in standard medium-scale models. Workers, on the other hand, invest in risk-free claims on government debt subject to portfolio adjustment costs. This allows the model to do a better job of replicating the dynamics of both aggregate consumption and marginal propensities to consume (MPC) without having to rely on modeling devices such as habits on consumption, for example.

The fact that agents and MPCs are heterogeneous brings us to the second major feature, which is an explicit government budget constraint and different types of fiscal policies. Most medium-scale DSGE models cannot speak to the effects of transfer and redistributive policies given the assumption of a single representative agent who is unconstrained and for whom the Ricardian Equivalence holds. In our model, the assumption of limited heterogeneity allows for the analysis of redistributive policies such as lump-sum transfers. In our model, there is a well-defined government budget constraint. Importantly, and differently from other models, we measure the levels of government consumption and transfers directly from the data, which allows us to model fiscal deficits and therefore analyze the effects of shocks on variables such as government debt. Most medium-scale DSGE models treat government consumption as the residual of the income-expenditure identity in a closed economy setting, $Y = C + I + G$. Since we treat government consumption as an observable, and therefore observe all components of domestic expenditure, this requires adding measurement error to the GDP growth observation equation – a reduced-form modeling of the trade balance.

There is a long tradition of multiple-representative agent New Keynesian models in economics as a (limited) means to capture household heterogeneity (Galí et al., 2007). The standard approach, which typically consists of two types of agents – Ricardian and hand-to-mouth – has well-known issues that limit its applicability for quantitative work. A more recent literature detects, highlights, and proposes solutions to some of these issues (Bilbiie, 2019; Broer et al., 2020; Debortoli and Galí, 2024). Two major issues are: i) the fact that when working agents receive firm profits, the cyclicality of this variable generates implausible income effects over labor supply; and ii) strict hand-to-mouth agents have a MPC equal to 1, which results in implausible responses to fiscal policy shocks such as transfers. We adopt the parsimonious framework proposed by Cantore and Freund (2021), which addresses both of these issues by assuming that the agents who own firms do not supply labor, and that the agents who work face soft constraints on portfolio adjustment, which raises their MPC but does not make them completely constrained.

Purpose and structure. This document is written as a technical guide aimed at those who are interested in the more practical aspects and details of model development and usage. The model is continuously maintained and improved, and the plan is to update this document accordingly.

The rest of the document is structured as follows: Section 2 is a technical description of the model. Section 3 presents the full list of equilibrium conditions. Section 4 describes the calibration and estimation of the model. Finally, Section 5 presents some of the model output.

2 Model

Time is discrete and infinite, $t = 0, 1, 2, \ldots$. The agents in the economy are: two types of households (capitalists and workers), labor unions, intermediate goods producers, final goods producers, the fiscal authority, and the monetary authority. The numeraire is a final consumption good that stands for personal consumption expenditures excluding food and energy, i.e. core PCE.

2.1 Stochastic trends: TFP and labor disutility

The model features two stochastic trends: labor-augmenting total factor productivity Z_t, and disutility of labor ξ_t. These variables grow at gross rates Γ_t^Z, Γ_t^N, respectively:

$$Z_t = \Gamma_t^Z Z_{t-1} \tag{1}$$

$$\xi_t = \Gamma_t^N \xi_{t-1} \tag{2}$$

These variables define the stochastic trend for most real quantities in the model, which is given by $Z_t \times \xi_t$, with gross growth rate $\Gamma_t \equiv \Gamma_t^Z \times \Gamma_t^N$.

2.2 Households

There are two types of households: workers in fixed share $\lambda \in [0, 1]$, and capitalists in fixed share $1 - \lambda$. Capitalists are similar to the representative agent in medium-scale DSGE models: they do not face any sort of borrowing or portfolio constraints and are the residual owners of financial and real claims in the economy. They are Ricardian agents due to the absence of borrowing constraints, as they internalize the fact that increases in government debt correspond to future taxation. This implies that their marginal propensity to consume (MPC) will be relatively low. Workers, on the other hand, save in risk-free government debt subject to portfolio adjustment costs. This raises their MPC, but, importantly, does not make them fully static/constrained as in other TANK models, which would imply a MPC equal to 1.

2.2.1 Capitalists

Capitalists are similar to the representative household in standard DSGE models. These households derive utility from the final consumption good, do not supply any labor, invest in physical capital and government debt, and choose the utilization rate of physical capital.

We can write their problem in recursive form as:

$$V^s(B_{t-1}^s, K_{t-1}, I_{t-1}) = \max_{C_t^s, B_t^s, I_t, K_t, \nu_t} \chi_t \log(C_t^s) + \beta \mathbb{E}_t V^s(B_t^s, K_t, I_t) \tag{3}$$

$$\text{s.t.} \quad P_t C_t^s (1 + \tau^c) + P_t \frac{B_t^s}{R_t} + P_t I_t = P_{t-1} B_{t-1}^s + (1 - \tau_t^d) P_t (\nu_t R_t^k K_{t-1} + D_t) - P_t A(\nu_t) K_{t-1} + P_t T_t \tag{4}$$

$$K_t = (1 - \delta) K_{t-1} + \zeta_t [1 - S(I_t / I_{t-1})] I_t \tag{5}$$

where C_t^s is consumption, τ^c is a flat tax over consumption expenditures, B_t^s is government debt held by capitalists, K_t is the physical stock of capital, I_t is investment in physical capital, ν_t is the utilization rate of physical capital, P_t is the price level in terms of the final consumption good, R_t is the nominal interest rate, R_t^k is the real return on capital, D_t are profits from goods producers, τ_t^d is a linear capital income tax, and T_t are government lump-sum transfers.

Equation (3) defines the value function of the capitalist. We assume that these agents have log utility over consumption. Typical medium-scale models allow for habits on consumption in order to match the slow response of aggregate consumption to certain types of shocks. One of the advantages of the way we introduce heterogeneity is that this becomes less important to capture the response of consumption to certain types of shocks. χ_t is a marginal utility shock that can be thought of as an "aggregate demand shock": it raises the marginal utility of consumption today, raising household consumption everything else constant and playing a similar role to that of discount factor shocks.

Equation (4) is the budget constraint of the capitalist, equating uses of income to sources of income. The household spends in final consumption, invests in government bonds discounted at the one-period nominal interest rate R_t, and invests in physical capital. The household earns income from government debt repayments, as well as from utilized capital and firm profits, both of which are taxed at rate τ_t^d. Finally, $A(\nu)$ is a convex function that reflects capital utilization costs.

Equation (5) is the law of motion for physical capital: capital available tomorrow is equal to capital available today net of depreciation δ plus new capital formed through gross investment I_t. Investment is subject to adjustment costs represented by the function S. ζ_t is a shock to the marginal efficiency of investment that affects the economy's ability to convert final consumption goods into physical capital. These shocks have been shown to play an important role in the business cycle (Justiniano et al., 2011).

Optimality conditions. The capitalists' stochastic discount factor is given by:

$$m_{t,t+k}^s \equiv \beta \frac{\chi_{t+k}/C_{t+k}^s}{\chi_t/C_t^s} \tag{6}$$

The optimality conditions are as follows. First, there is an Euler equation for government debt:

$$1 = R_t \mathbb{E}_t \left[\frac{m_{t,t+1}^s}{\Pi_{t+1}} \right] \vartheta_t \tag{7}$$

where $\Pi_t \equiv P_t/P_{t-1}$ is the gross inflation rate. ϑ_t is a convenience yield shock that drives an exogenous wedge between the required return on government debt and capital as in Del Negro et al. (2017).[1]

Second, the FOC for capital is given by:

$$Q_t^k = \mathbb{E}_t m_{t,t+1}^s \left[(1-\tau_{t+1}^d)\nu_{t+1} R_{t+1}^k + (1-\delta) Q_{t+1}^k - A(\nu_{t+1}) \right] \tag{8}$$

where Q_t^k is the marginal value of a unit of physical capital, or Tobin's Q. The optimality condition for physical investment is given by:

$$1 - Q_t^k \zeta_t \left[1 - S_t - \frac{I_t}{I_{t-1}} S_t' \right] = \mathbb{E}_t m_{t,t+1}^s \left[Q_{t+1}^k \zeta_{t+1} \left(\frac{I_{t+1}}{I_t} \right)^2 S_{t+1}' \right] \tag{9}$$

where $S_t \equiv S(I_t/I_{t-1}), S_t' \equiv S'(I_t/I_{t-1})$. Finally, the optimal condition for capital utilization is:

$$R_t^k = A'(\nu_t) \tag{10}$$

[1] This can be microfounded with bonds in the utility function, reflecting liquidity benefits of these assets that are not explicitly modeled, such as use as collateral for financial transactions or to satisfy financial regulatory requirements.

2.2.2 Workers

Workers derive utility from the final consumption good, supply labor, receive transfers from the government, and save in government bonds subject to portfolio adjustment costs. Their value function is given by:

$$V^w(B^w_{t-1}) = \max_{C^w_t, B^w_t} \chi_t[\log(C^w_t) - v(N_t; \xi_t)] + \beta \mathbb{E}_t V^w(B^w_t) \tag{11}$$

$$\text{s.t.} \qquad P_t C^w_t (1+\tau^c) + P_t \frac{B^w_t + \Psi(B^w_t)}{R_t} = (1-\tau^l_t) W_t N_t + P_{t-1} B^w_{t-1} + P_t T_t + P_t F_t \tag{12}$$

where C^w_t is worker consumption, B^w_t are worker holdings of government bonds, $v(N_t; \xi_t)$ is disutility from labor supplied, N_t are hours worked, τ^l_t is a linear tax on labor income, W_t is the nominal wage, and $\Psi(B^w_t)$ is a convex function that represents portfolio adjustment costs. In practice, we assume that this is a quadratic function of deviations of B^w_t holdings from a baseline value, as described in more detail later. Note that we pre-multiply flow utility by χ_t so that this shock does not affect the relative preference between consumption and leisure, so as not to distort labor supply. We also assume that portfolio costs are rebated to workers as lump-sum transfers F_t, so as to prevent them from generating significant income effects.

Optimality conditions. We define the SDF of workers in an analogous way to that of the capitalist:

$$m^w_{t,t+k} \equiv \beta \frac{\chi_{t+k} (C^w_{t+k})^{-1}}{\chi_t (C^w_t)^{-1}} \tag{13}$$

The Euler equation for the worker is then given by:

$$1 = R_t \vartheta_t \mathbb{E} \left[\frac{m^w_{t,t+1}}{\Pi_{t+1}} \frac{1}{1+\Psi'(B^w_t)} \right] \tag{14}$$

Notice that the savings decision is distorted by the derivative of Ψ: in an environment without any adjustment costs, the Euler equation of the worker would be the same as that of the capitalists' (7). If adjustment costs are infinite, workers are effectively hand-to-mouth as they cannot adjust their asset holdings, and consumption is pinned down by the budget constraint (12), generating a MPC of 1. A finite derivative for this function allows for an intermediate case. For example, it allows the worker to smooth out income that is received from the government instead of having to spend it right away, which would be the case in a pure TANK model.

2.3 Labor unions

The worker does not choose how much labor to supply; this decision is taken, instead, by labor unions, a convenient way to introduce nominal wage rigidities

We begin by assuming that the worker supplies a continuum of varieties of labor indexed by

j. We assume that the disutility of labor for the worker takes the following form:

$$v(N;\xi) = \frac{1}{\xi^{1+\varphi}} \int \frac{N(j)^{1+\varphi}}{1+\varphi} \mathrm{d}j \tag{15}$$

Each of these labor varieties is supplied to a union, which sets the nominal wage for the specific variety $W_t(j)$. These labor varieties are then supplied to a labor aggregator firm that converts them into a labor composite N_t.

Labor aggregator. The labor aggregator firm has access to a CES technology that converts labor varieties $N_t(j)$ into a final labor composite N_t that is then supplied to intermediate goods producers. The labor aggregator hires each variety at wage $W_t(j)$ and then supplies the final labor composite at wage W_t. The problem of the labor aggregator is given by:

$$\max_{N_t, \{N_t(j)\}} W_t N_t - \int W_t(j) N_t(j) \mathrm{d}j \tag{16}$$

$$\text{s.t.} \qquad N_t = \left[\int N_t(j)^{\frac{1}{\mu_t^w}} \mathrm{d}j \right]^{\mu_t^w} \tag{17}$$

where (17) is a CES technology that converts the continuum of labor varieties into the final labor composite. μ_t^w is a transformation of the elasticity of substitution between varieties,which determines the markup. We assume that it follows an exogenous process, reflecting fluctuations in labor market markups. The solution to the labor aggregator's problem yields labor variety-specific demand curves of the following type:

$$N_t(j) = \left[\frac{W_t(j)}{W_t} \right]^{-\frac{\mu_t^w}{\mu_t^w - 1}} N_t \tag{18}$$

The aggregate wage level is implicitly defined as:

$$W_t^{-\frac{1}{\mu_t^w - 1}} = \int W_t(j)^{-\frac{1}{\mu_t^w - 1}} \mathrm{d}j \tag{19}$$

Labor union problem. Each union j chooses how much labor to supply $N_t(j)$ and what wage to set $W_t(j)$ subject to the demand function for that specific variety (18) and adjustment costs à la Rotemberg. These adjustment costs make it costly to change the nominal wage for that specific variety.

The union chooses $W_t(j)$ to maximize the present discounted value of wage income, given disutility of labor supply. The recursive formulation of the union's problem is given by:

$$V^u[W_{t-1}(j)] = \max_{W_t(j),N_t(j)} [W_t(j) - P_t MRS_t(j)]N_t(j) - P_t \frac{\eta_w}{2} N_t \left[\frac{W_t(j)}{W_{t-1}(j)} \frac{1}{\Pi_t^{w,index}} - 1 \right]^2 + \beta \mathbb{E}_t \frac{V^u[W_t(j)]}{\Pi_{t+1}} \tag{20}$$

$$\text{s.t.} \qquad N_t(j) = \left[\frac{W_t(j)}{W_t} \right]^{-\frac{\mu_t^w}{\mu_t^w - 1}} N_t$$

The union's flow payoff is composed of nominal labor income $W_t(j)N_t(j)$ minus disutility of labor expressed in terms of nominal dollars, $P_t MRS_t(j)N_t(j)$. The second term is the Rotemberg menu cost: the union faces convex costs of adjusting $W_t(j)$ relative to the nominal wage from the previous period. $\Pi_t^{w,index}$ is an indexation term that allows for some free adjustment of wages.

$MRS_t(j)$ is equal to the marginal rate of substitution for the worker:

$$MRS_t(j) = -\frac{v'(N_t;\xi_t)}{u'(C_t^w)} = \frac{(1+\tau_c)C_t^w N_t(j)^\varphi}{(1-\tau_t^l)\xi_t^{1+\varphi}} \tag{21}$$

That is, it represents the disutility of labor expressed in terms of units of consumption. The first-order condition for the union problem in (20) is:

$$\begin{aligned} &N_t(j)\left[1 + \varphi MRS_t(j) \frac{\mu_t^w}{\mu_t^w - 1} \frac{P_t}{W_t(j)}\right] - [W_t(j) - P_t MRS_t(j)] \frac{\mu_t^w}{\mu_t^w - 1} \frac{N_t(j)}{W_t(j)} \\ &- \eta_w N_t \frac{P_t}{W_{t-1}(j)\Pi_t^{w,index}} \left[\frac{W_t(j)}{W_{t-1}(j)\Pi_t^{w,index}} - 1\right] + \beta \eta_w \mathbb{E}_t N_{t+1} \frac{P_{t+1}W_{t+1}(j)}{W_t(j)^2 \Pi_{t+1}^{w,index}\Pi_{t+1}} \left[\frac{W_{t+1}(j)}{W_t(j)\Pi_{t+1}^{w,index}} - 1\right] = 0 \end{aligned}$$

We assume that all unions behave symmetrically, setting $W_t(j) = W_t$ and $N_t(j) = N_t$ for all j. Define nominal wage inflation as $\Pi_t^w = W_t / W_{t-1}$. This allows us to simplify the above expression and arrive at the wage Phillips curve that governs wage inflation:

$$\frac{W_t}{P_t} + \frac{\mu_t^w}{\mu_t^w - 1}\left[MRS_t(1+\varphi) - \frac{W_t}{P_t}\right] - \eta_w \frac{\Pi_t^w}{\Pi_t^{w,index}} \left(\frac{\Pi_t^w}{\Pi_t^{w,index}} - 1\right) + \beta \eta_w \mathbb{E}_t \frac{N_{t+1}}{N_t} \frac{\Pi_{t+1}^w}{\Pi_{t+1}^{w,index}} \left(\frac{\Pi_{t+1}^w}{\Pi_{t+1}^{w,index}} - 1\right) = 0 \tag{22}$$

2.4 Goods producers

As with the labor supply block, there are two types of goods-producing firms in this economy. First, there are final goods producers, who convert intermediate goods varieties into a final non-durable good using a CES aggregator. Each of those intermediate varieties is in turn produced by monopolistically competitive producers who hire physical capital and labor, and set nominal prices subject to menu costs.

Final goods producers. The representative final goods producer combines a continuum of varieties indexed by k using a CES aggregator to produce final nondurable output. The problem of this producer is given by:

$$\max_{Y_t, \{Y_t(k)\}} P_t Y_t - \int P_t(k) Y_t(k) \mathrm{d}k$$

$$\text{s.t.} \qquad Y_t = \left[\int Y_t(k)^{\frac{1}{\mu_t^p}} \mathrm{d}k \right]^{\mu_t^p}$$

where $P_t(k)$ is the price of each variety. Notice that we allow the markup to be time-varying, μ_t^p. This problem gives rise to variety-specific demand curves:

$$Y_t(k) = \left[\frac{P_t(k)}{P_t} \right]^{-\frac{\mu_t^p}{\mu_t^p - 1}} Y_t \tag{23}$$

The solution to this problem also defines the price level as a function of the prices for each variety:

$$P_t^{-\frac{1}{\mu_t^p - 1}} = \int P_t(k)^{-\frac{1}{\mu_t^p - 1}} \mathrm{d}k$$

Intermediate goods producers. A continuum of intermediate goods producers rent capital and hire labor to produce variety k. They also choose the nominal price of their respective variety, subject to menu costs. The recursive formulation of their problem is:

$$\begin{aligned} V^f[P_{t-1}(k)] = \max_{P_t(k), Y_t(k), N_t(k), K_t^u(k)} & P_t(k) Y_t(k) - W_t N_t(k) - P_t R_t^k K_t^u(k) \\ & - P_t \frac{\eta_p}{2} Y_t \left[\frac{P_t(k)}{P_{t-1}(k)} \frac{1}{\Pi_t^{p,index}} - 1 \right]^2 + \mathbb{E}_t m_{t,t+1}^s V^f[P_t(k)] \end{aligned} \tag{24}$$

$$\text{s.t.} \qquad Y_t(k) = \left[\frac{P_t(k)}{P_t} \right]^{-\frac{\mu_t^p}{\mu_t^p - 1}} Y_t \tag{25}$$

$$Y_t(k) \leq (K_t^u(k))^{\alpha} (Z_t N_t(k))^{1-\alpha} \tag{26}$$

where $K_t^u(k)$ is the quantity of capital rented by producer of variety k, and $\Pi_t^{p,index}$ is an indexation term that allows the firm to undertake some free adjustment of nominal prices.

The solution to this problem is standard. It is convenient to first derive the optimal input mix that minimizes costs for a given level of production. That is given by:

$$K_t^u(k) = \frac{\alpha}{1-\alpha} \frac{W_t / P_t}{R_t^k} N_t(k) \tag{27}$$

This then allows us to define the real marginal cost of producing one unit of output as

$$MC_t(k) = Z_t^{-(1-\alpha)} \left(\frac{R_t^k}{\alpha}\right)^{\alpha} \left(\frac{W_t/P_t}{1-\alpha}\right)^{1-\alpha} \tag{28}$$

We can then use the expression for the marginal cost to recast (24) as a problem with two control variables: the varietal price and output. Taking first-order conditions and, again, imposing symmetry across firms $P_t(k) = P_t, \forall k$ yields the New Keynesian Phillips curve (NKPC):

$$\frac{\Pi_t}{\Pi_t^{p,index}} \left(\frac{\Pi_t}{\Pi_t^{p,index}} - 1\right) = \mathbb{E}_t \left[m_{t,t+1}^s \frac{Y_{t+1}}{Y_t} \frac{\Pi_{t+1}}{\Pi_{t+1}^{p,index}} \left(\frac{\Pi_{t+1}}{\Pi_{t+1}^{p,index}} - 1\right)\right] + \frac{1}{\eta_p(\mu_t^p - 1)} \left(\mu_t^p MC_t - 1\right) \tag{29}$$

Finally, total profits from intermediate producers are rebated to the capitalists:

$$P_t D_t = P_t Y_t - W_t N_t - P_t R_t^k K_t^u - P_t \frac{\eta_p}{2} Y_t \left[\frac{P_t(k)}{P_{t-1}(k)} \frac{1}{\Pi_t^{p,index}} - 1\right]^2$$

2.5 Fiscal authority

The fiscal component of the model is more detailed than what is usually found in medium-scale DSGEs, and follows closely Leeper et al. (2017) and Faria-e-Castro (2024). The fiscal authority engages in government consumption G_t, runs a social program composed of lump-sum transfers T_t, issues nominal debt B_t^g, and levies consumption taxes τ^c, distortionary labor income taxes τ_t^l, and capital income taxes τ_t^d. The government budget constraint is:

$$P_t G_t + P_t T_t + P_{t-1} B_{t-1}^g = \tau^c P_t C_t + \tau_t^l W_t N_t + \tau_t^d P_t (\nu_t R_t^k K_{t-1} + D_t) + P_t \frac{B_t^g}{R_t} \tag{30}$$

where $C_t = \lambda C_t^w + (1-\lambda) C_t^s$ is aggregate consumption. Since some agents are non-Ricardian and taxes are distortionary, the timing of deficits matters. We assume that labor and capital income taxes follow fiscal rules that respond to deviations of the debt-to-GDP ratio from its steady state value:

$$\tau_t^l = (\tau_{t-1}^l)^{\rho_{\tau,l}} \left[\bar{\tau}^l \left(\frac{B_{t-1}^g / Y_{t-1}}{\bar{B}^g / \bar{Y}}\right)^{\phi_{\tau,l}}\right]^{1-\rho_{\tau,l}} \tag{31}$$

$$\tau_t^d = (\tau_{t-1}^d)^{\rho_{\tau,d}} \left[\bar{\tau}^d \left(\frac{B_{t-1}^g / Y_{t-1}}{\bar{B}^g / \bar{Y}}\right)^{\phi_{\tau,d}}\right]^{1-\rho_{\tau,d}} \tag{32}$$

where $\rho_{\tau,x}$ are parameters that govern the persistence of tax rates for $x = l, d$, and $\phi_{\tau,x}$ govern the speed of tax adjustment. If $\phi_{\tau,x}$ is low, taxes do not respond much to fluctuations in the debt-to-GDP ratio, and so fiscal expansions will tend to be primarily deficit-financed. Debt is thus the residual instrument that adjusts to satisfy the government budget constraint. Finally, we assume that consumption taxes are constant at τ^c, as in Leeper et al. (2017).

2.6 Monetary authority

The central bank follows a version of a Taylor rule:

$$R_t = R_{t-1}^{\rho_r} \left[\bar{r} \Pi_t^* \left(\frac{\Pi_t}{\Pi_t^*} \right)^{\phi_\Pi} \left(\frac{Y_t}{\Gamma_t Y_{t-1}} \right)^{\phi_Y} \right]^{1-\rho_r} \mathrm{mp}_t \tag{33}$$

The rule defines the short-term nominal rate as the product of an autoregressive term that captures policy inertia and a target rate. The target rate's intercept is given by the product of the steady state real interest rate $\bar{r}$ and the central bank's time-varying inflation target Π_t^*. The target rate responds positively to deviations of inflation from this target, as well as to fluctuations in output that do not reflect the stochastic trends embedded in Γ_t. Finally, mp_t is a monetary policy shock that stands for non-systematic deviations of monetary policy from the rule.

2.7 Aggregate resource constraint

Summing over the budget constraints of both types of households and government, and simplifying, we arrive at the aggregate resource constraint:

$$C_t + G_t + I_t = Y_t \left[1 - \frac{\eta_p}{2} \left(\frac{\Pi_t}{\Pi_t^{p,index}} - 1 \right)^2 \right] - A(\nu_t) K_{t-1}$$

Total sources of domestic expenditure are aggregate consumption C_t, government consumption G_t, and investment in physical capital I_t. Additionally, there are utilization costs of capital and product price adjustment costs.

2.8 Functional Forms

Capital utilization. In equilibrium, capital that is utilized by firms must be consistent with the utilization rate chosen by the owners of capital. Thus we have that utilized capital K_t^u is given by:

$$K_t^u = \nu_t K_{t-1}$$

For the cost of capital utilization $A(\nu_t)$, we use the following function:

$$A(\nu_t) = \kappa_a(\nu_t - 1) + 0.5\sigma_a(\nu_t - 1)^2$$

Notice that it satisfies the usual desirable properties for such function:

$$A(1) = 0$$
$$A'(1) = \kappa_a (= \bar{R}^k)$$
$$\frac{A''(1)}{A'(1)} = \frac{\sigma_a}{\kappa_a}$$

Investment adjustment costs. We assume a quadratic functional form for the costs of deviation of the growth rate of physical investment from its trend:

$$S(I_t/I_{t-1}) = \frac{\psi_i}{2}\left(I_t/I_{t-1} - \bar{\Gamma}\right)^2$$

where $\bar{\Gamma}$ is the stationary growth rate of output and of most real quantities in the model.

Portfolio adjustment costs. We assume a simple quadratic cost function over deviations of portfolio holdings from a baseline value:

$$\Psi_t(B_t^w) = \frac{\psi_w}{2Z_t\xi_t}(B_t^w - Z_t\xi_t\bar{B}^w)^2$$

where $Z_t\xi_t$ is the stochastic trend for output.

Price and wage indexation. We assume that the indexation terms are weighted averages of inflation in the past period and the inflation targe:

$$\Pi_t^{p,index} = (\Pi_{t-1})^{\iota_p}(\Pi_t^*)^{1-\iota_p}$$
$$\Pi_t^{w,index} = \bar{\Gamma}^Z(\Pi_{t-1})^{\iota_w}(\Pi_t^*)^{1-\iota_w}$$

For wages, the indexation term is multiplied by the steady state growth rate of labor-augmenting TFP growth $\bar{\Gamma}$, which is the steady state growth rate of real wages.

2.9 Structural shocks

There are 11 structural shock series in the model. All shocks follow AR(1) processes in logs:

$$\log x_t = (1-\rho_x)\log\bar{x} + \rho_x \log x_{t-1} + \sigma_x\varepsilon_t^x$$

where $\varepsilon_t^x \sim \mathcal{N}(0,1)$ are standard Normal innovations.

1. Γ_t^Z is the growth rate of labor-augmenting TFP.
2. Γ_t^N is the growth rate of the labor disutility term.

3. ζ_t is the marginal efficiency of investment that governs the rate of transformation of final consumption goods to physical capital.

4. μ_t^p is the product price markup shock.

5. μ_t^w is the wage markup shock.

6. χ_t is a shock to the marginal utility of both workers and capitalists. It is similar to a discount factor shock in the sense that it changes how households value consumption across time.

7. ϑ_t is the convenience yield or risk premium shock that governs the relative preference for government bonds over physical capital. This shock drives a wedge between the rates of return of these two assets.

8. G_t is the process for government consumption of goods and services.

9. T_t are government transfers to households.

10. mp_t is the monetary policy shock that drives deviations of the policy rate from what would be implied by the Taylor rule.

11. Π_t^* is the time-varying inflation target of the Fed. This term is helpful to capture the gradual decline in inflation since the 1980s, and can reflect structural changes in the way monetary policy is conducted.

We classify these 11 shocks into 5 broad categories: supply $(\Gamma_t^Z, \Gamma_t^B, \zeta_t, \mu_t^p, \mu_t^w)$, demand (χ_t, ϑ_t), fiscal (G_t, T_t), and monetary (mp_t, Π_t^*). This classification is primarily useful to disentangle movements in variables that are driven by policy vs. non-policy impulses.

2.10 Flexible price economy

The flexible price economy is an economy subject to the same shocks and with the same equilibrium conditions as the baseline economy, but with the following restrictions:

1. No nominal rigidities and product markup shocks. The product markup is assumed to be constant $\mu_t^p = \bar{\mu}^p, \forall t$ and the NKPC in (29) is replaced by a static pricing condition for the firm:
$$\bar{\mu}^p MC_t = 1$$

2. No wage rigidities and wage markup shocks. The wage markup is assumed to be constant $\mu_t^w = \bar{\mu}^w, \forall t$ and the wage Phillips curve in (22) is replaced by a static labor supply condition:
$$\frac{W_t}{P_t} = MRS_t(1+\varphi)$$

3. Inflation is at the Fed's time-varying target, $\Pi_t = \Pi_t^*$.

Flexible price economy variables are denoted with a superscript f. Of most relevance are the natural level of output Y_t^f that allows us to compute the output gap Y_t / Y_t^f, and the real interest rate r_t^f that corresponds to the neutral level of the interest rate following the definition in Woodford (2003).

3 Full List of Equilibrium Conditions

Due to stochastic trends, we define the equilibrium of the model in terms of detrended variables. Let $x_t = \frac{X_t}{Z_t \xi_t}$ for any variable x, except labor and real wages. The relevant stochastic trend for hours is ξ_t, while the relevant stochastic trend for wages is Z_t. Thus:

$$n_t = \frac{N_t}{\xi_t}$$
$$w_t = \frac{W_t / P_t}{Z_t}$$

Recall that we define $\Gamma_t \equiv \Gamma_t^Z \times \Gamma_t^N$ as the growth rate of the stochastic trend for output. The full list of equilibrium conditions in terms of detrended variables follows.

Worker households:

$$\text{SDF:} \qquad m^w_{t,t+1} = \frac{\beta}{\Gamma_{t+1}} \frac{c^w_t}{c^w_{t+1}} \frac{\chi_{t+1}}{\chi_t} \tag{34}$$

$$\text{Euler eq:} \qquad 1 = R_t \vartheta_t \mathbb{E}\left[\frac{m^w_{t,t+1}}{\Pi_{t+1}} \frac{1}{1+\psi_w(b^w_t - \bar{B}^w)}\right] \tag{35}$$

$$\text{budget const.} \qquad (1+\tau_c)c^w_t + \frac{b^w_t}{R_t} = (1-\tau^l_t) w_t \frac{n_t}{\lambda} + \frac{b^w_{t-1}}{\Pi_t \Gamma_t} + t_t \tag{36}$$

Capitalist households:

$$\text{SDF:} \qquad m^s_{t,t+1} = \frac{\beta}{\Gamma_{t+1}} \frac{c^s_t}{c^s_{t+1}} \frac{\chi_{t+1}}{\chi_t} \tag{37}$$

$$\text{Euler eq:} \qquad 1 = R_t \vartheta_t \mathbb{E}_t\left[\frac{m^s_{t,t+1}}{\Pi_{t+1}}\right] \tag{38}$$

$$\text{utilization:} \qquad R^k_t = A'(\nu_t) \tag{39}$$

$$\text{Tobin's Q:} \qquad Q^k_t = \mathbb{E}_t m^s_{t,t+1}\left[(1-\tau^d_{t+1}) R^k_{t+1}\nu_{t+1} + (1-\delta)Q^k_{t+1} - A(\nu_{t+1})\right] \tag{40}$$

$$\text{investment:} \qquad 1 - Q^k_t \zeta_t \left[1 - S_t - \Gamma_t \frac{i_t}{i_{t-1}} S'_t\right] = \mathbb{E}_t m^s_{t,t+1}\left[Q^k_{t+1}\zeta_{t+1}\left(\Gamma_{t+1}\frac{i_{t+1}}{i_t}\right)^2 S'_{t+1}\right] \tag{41}$$

(42)

Labor markets:

$$\text{wage NKPC:} \quad w_t + \frac{\mu_t^w}{\mu_t^w - 1}\left[mrs_t(1+\varphi) - w_t\right] - \eta_w \frac{\Pi_t^w}{\Pi_t^{w,index}}\left(\frac{\Pi_t^w}{\Pi_t^{w,index}} - 1\right) \tag{43}$$

$$+\beta\eta_w \mathbb{E}_t \frac{n_{t+1}}{n_t}\frac{\Pi_{t+1}^w}{\Pi_{t+1}^{w,index}}\left(\frac{\Pi_{t+1}^w}{\Pi_{t+1}^{w,index}} - 1\right) = 0$$

$$\text{MRS:} \quad mrs_t = \frac{(1+\tau_c)c_t^w \bar{\bar{\xi}}}{(1-\tau_t^l)}(n_t/\lambda)^{\varphi} \tag{44}$$

$$\text{wage indexation:} \quad \Pi_t^{w,index} = \bar{\Gamma}^Z(\Pi_t)^{\iota_w}(\Pi_t^*)^{1-\iota_w} \tag{45}$$

$$\text{wage inflation:} \quad \Pi_t^w = \frac{w_t}{w_{t-1}}\Gamma_t^Z \Pi_t \tag{46}$$

Capital and investment:

$$\text{LoM capital:} \quad k_t = (1-\delta)\frac{k_{t-1}}{\Gamma_t} + \zeta_t[1 - S(\Gamma_t i_t / i_{t-1})]i_t \tag{47}$$

$$\text{utilized capital:} \quad k_t^u = \frac{\nu_t}{\Gamma_t}k_{t-1} \tag{48}$$

Firms

$$\text{NKPC:} \quad \frac{\Pi_t}{\Pi_t^{index}}\left(\frac{\Pi_t}{\Pi_t^{index}} - 1\right) = \mathbb{E}_t\left[m_{t,t+1}^s \frac{y_{t+1}}{y_t}\Gamma_{t+1}\frac{\Pi_{t+1}}{\Pi_{t+1}^{index}}\left(\frac{\Pi_{t+1}}{\Pi_{t+1}^{index}} - 1\right)\right]$$

$$+\frac{1}{\eta_p(\mu_t^p - 1)}\left(\mu_t^p mc_t - 1\right) \tag{49}$$

$$\text{marginal cost:} \quad mc_t = \left(\frac{R_t^k}{\alpha}\right)^{\alpha}\left(\frac{w_t}{1-\alpha}\right)^{1-\alpha} \tag{50}$$

$$\text{indexation:} \quad \Pi_t^{index} = \Pi_{t-1}^{\iota_\Pi}(\Pi_t^*)^{1-\iota_\Pi} \tag{51}$$

$$\text{production:} \quad y_t = (k_t^u)^{\alpha} n_t^{1-\alpha} \tag{52}$$

$$\text{input mix:} \quad k_t^u = \frac{\alpha}{1-\alpha}\frac{w_t}{R_t^k}n_t \tag{53}$$

$$\text{resource constraint:} \quad c_t + g_t + i_t + A(\nu_t)\frac{k_{t-1}}{\Gamma_t} = y_t\left[1 - 0.5\eta_p\left(\frac{\Pi_t}{\Pi_t^{index}} - 1\right)^2\right] \tag{54}$$

$$\text{aggregate consumption:} \quad c_t = \lambda c_t^w + (1-\lambda)c_t^s \tag{55}$$

Government:

$$\text{govt bc:} \qquad g_t + t_t + \frac{b^g_{t-1}}{\Pi_t \Gamma_t} = \tau^c c_t + \tau^l_t w_t n_t + \tau^d_t (R^k_t k^u_t + d_t) + \frac{b^g_t}{R_t} \tag{56}$$

$$\text{fiscal rule I:} \qquad \tau^l_t = (\tau^l_{t-1})^{\rho_{\tau,l}} \left[\bar{\tau}^l \left(\frac{b^g_{t-1}/y_{t-1}}{\bar{B}^g/\bar{Y}} \right)^{\phi_{\tau,l}} \right]^{1-\rho_{\tau,l}} \tag{57}$$

$$\text{fiscal rule II:} \qquad \tau^d_t = (\tau^d_{t-1})^{\rho_{\tau,d}} \left[\bar{\tau}^d \left(\frac{b^g_{t-1}/y_{t-1}}{\bar{B}^g/\bar{Y}} \right)^{\phi_{\tau,d}} \right]^{1-\rho_{\tau,d}} \tag{58}$$

$$\text{Taylor rule:} \qquad R_t = R^{\rho_r}_{t-1} \left[\bar{r} \Pi^*_t \left(\frac{\Pi_t}{\Pi^*_t} \right)^{\phi_\Pi} \left(\frac{y_t}{y_{t-1}} \right)^{\phi_Y} \right]^{1-\rho_r} \text{mp}_t \tag{59}$$

Other:

$$\text{firm profits:} \qquad d_t = y_t - w_t n_t - R^k_t k^u_t - 0.5 \eta_p y_t \left(\frac{\Pi_t}{\Pi^{index}_t} - 1 \right)^2 \tag{60}$$

$$\text{real interest rate:} \qquad r_t = \frac{R_t}{\mathbb{E}_t \Pi_{t+1}} \tag{61}$$

Shocks:

$$\text{TFP:} \qquad \log \Gamma^Z_t = (1 - \rho_{\Gamma^Z}) \log \bar{\Gamma}^Z + \rho_{\Gamma^Z} \log \Gamma^Z_{t-1} + \sigma_{\Gamma^Z} \varepsilon^{\Gamma^Z}_t \tag{62}$$

$$\text{labor disutility:} \qquad \log \Gamma^N_t = (1 - \rho_{\Gamma^N}) \log \bar{\Gamma}^N + \rho_{\Gamma^N} \log \Gamma^N_{t-1} + \sigma_{\Gamma^N} \varepsilon^{\Gamma^N}_t \tag{63}$$

$$\text{MEI:} \qquad \log \zeta_t = (1 - \rho_\zeta) \log \bar{\zeta} + \rho_\zeta \log \zeta_{t-1} + \sigma_\zeta \varepsilon^\zeta_t \tag{64}$$

$$\text{price markup:} \qquad \log \mu^p_t = (1 - \rho_{\mu^p}) \log \bar{\mu}^p + \rho_{\mu^p} \log \mu^p_{t-1} + \sigma_{\mu^p} \varepsilon^{\mu^p}_t - \eta_{\mu^p} \sigma_{\mu^p} \varepsilon^{\mu^p}_{t-1} \tag{65}$$

$$\text{wage markup:} \qquad \log \mu^w_t = (1 - \rho_{\mu^w}) \log \bar{\mu}^w + \rho_{\mu^w} \log \mu^w_{t-1} + \sigma_{\mu^w} \varepsilon^{\mu^w}_t - \eta_{\mu^w} \sigma_{\mu^w} \varepsilon^{\mu^w}_{t-1} \tag{66}$$

$$\text{marginal utility:} \qquad \log \chi_t = (1 - \rho_\chi) \log \bar{\chi} + \rho_\chi \log \chi_{t-1} + \sigma_\chi \varepsilon^\chi_t \tag{67}$$

$$\text{convenience yield:} \qquad \log \vartheta_t = (1 - \rho_\vartheta) \log \bar{\vartheta} + \rho_\vartheta \log \vartheta_{t-1} + \sigma_\vartheta \varepsilon^\vartheta_t \tag{68}$$

$$\text{govt spending:} \qquad \log g_t = (1 - \rho_G) \log \bar{g} + \rho_G \log g_{t-1} + \sigma_G \varepsilon^G_t \tag{69}$$

$$\text{fiscal transfers:} \qquad \log t_t = (1 - \rho_T) \log \bar{t} + \rho_T \log t_{t-1} + \sigma_T \varepsilon^T_t \tag{70}$$

$$\text{monetary policy:} \qquad \log \text{mp}_t = (1 - \rho_{\text{mp}}) \log \bar{\text{mp}} + \rho_{\text{mp}} \log \text{mp}_{t-1} + \sigma_{\text{mp}} \varepsilon^{\text{mp}}_t \tag{71}$$

$$\text{inflation target:} \qquad \log \Pi^*_t = (1 - \rho_\Pi) \log \bar{\Pi} + \rho_\Pi \log \Pi^*_{t-1} + \sigma_\Pi \varepsilon^\Pi_t \tag{72}$$

The equilibrium conditions for the flexible price economy are the same as above, (34)-(72), but with the product and wage NKPC replaced by the respective static optimality conditions, and the Taylor rule replaced with constant inflation at target, $\Pi^f_t = \Pi^*_t$. These assumptions imply that neither markup nor monetary policy shocks affect the equilibrium of the flexible price economy. The natural rate of interest is computed from the Euler equation for capitalists:

$$r_t^f = [\vartheta_t \mathbb{E}_t m_{t,t+1}^{s,f}]^{-1} \tag{73}$$

4 Estimation and Calibration

We calibrate some parameters and estimate others on US data using standard Bayesian estimation techniques (Adjemian et al., 2024). This section describes the data, the set of calibrated parameters, and details of the model estimation.

4.1 Observation Equations.

We use 13 observable series to estimate the model. The observation equations are the following:

$$\text{GDP growth}_t = 400 \times (\log y_t - \log y_{t-1} + \log \Gamma_t^Z + \log \Gamma_t^N + me_t^y) \tag{74}$$

$$\text{Cons. growth}_t = 400 \times (\log c_t - \log c_{t-1} + \log \Gamma_t^Z + \log \Gamma_t^N) + cobs_{c,y} \tag{75}$$

$$\text{Inv. growth}_t = 400 \times (\log i_t - \log i_{t-1} + \log \Gamma_t^Z + \log \Gamma_t^N) + cobs_{i,y} \tag{76}$$

$$\text{Govt. cons. growth}_t = 400 \times (\log g_t - \log g_{t-1} + \log \Gamma_t^Z + \log \Gamma_t^N) + cobs_{g,y} \tag{77}$$

$$\text{Transfers growth}_t = 400 \times (\log t_t - \log t_{t-1} + \log \Gamma_t^Z + \log \Gamma_t^N) + cobs_{t,y} \tag{78}$$

$$\text{Wage growth}_t = 400 \times (\log w_t - \log w_{t-1} + \log \Gamma_t^Z) + cobs_{w,y} \tag{79}$$

$$\text{Hours growth}_t = 400 \times (\log n_t - \log n_{t-1} + \log \Gamma_t^N) \tag{80}$$

$$\text{FFR}_t = 100 \times (R_t^4 - 1) \tag{81}$$

$$\text{Core PCE inflation}_t = 100 \times (\Pi_t^4 - 1) \tag{82}$$

$$\text{TFP growth demeaned}_t = \log \Gamma_t^Z - \log \bar{\Gamma}^Z + \frac{\alpha}{1-\alpha}(\log \nu_t - \log \nu_{t-1}) + me_t^{tfp} \tag{83}$$

$$\text{10y inflation expectations}_t = 100 \times \left[\mathbb{E}_t \left(\prod_{i=1}^{40} \Pi_{t+i} \right)^{1/10} - 1 + me_t^{inflexp} \right] \tag{84}$$

$$\text{10y Treasury rate}_t = 100 \times \left[\mathbb{E}_t \left(\prod_{i=0}^{39} R_{t+i} \right)^{1/10} - 1 + me_t^{tp} \right] \tag{85}$$

$$\text{Convenience yield}_t = 100 \times \left[\mathbb{E}_t \left(\prod_{i=0}^{79} \vartheta_{t+i} \right)^{1/20} - 1 + me_t^{cy} \right] \tag{86}$$

where $cobs_{x,y}$ are calibrated constants that account for average historical differences in growth rates between variable x and output (Cairó et al., 2023), and me_t^x are AR(1) measurement error terms that serve two purposes. First, some of the observables may be measured with error, such as TFP growth. Second, the model abstracts from factors that could affect some of the observables. For example, we include measurement error in GDP growth since the model represents a closed economy, but in practice fluctuations in the trade balance affect this observable. Similarly, we include measurement error in the 10-year Treasury rate in order to capture the fact that a time-varying term premium exists in the data, while the model satisfies the expectation hypothesis. We assume that all measurement error terms have mean zero, with the exception of the term premium, whose mean tp we estimate. Finally, we include measurement error in inflation expectations to capture potential deviations from rational expectations, as well as on the convenience yield.

In summary, the estimation procedure involves 13 observable series, for 11 structural shocks plus 5 measurement error shocks.

4.2 Data

We use quarterly data for the US. Our sample begins in 1959Q1, which is the first date for which we can compute Core PCE inflation. The model is estimated using all data available up to the latest quarter, 2025Q2 in the case of the current version of this document. We now describe each of the series in more detail. Most data is extracted from FRED and we include the FRED mnemonics in parentheses. Figure 1 plots the observable series.

1. GDP growth is per-capita real GDP growth. We compute the annualized quarterly growth rate of nominal GDP (GDP) divided by the GDP deflator ($GDPDEF$) and civilian population over the age of 16 ($CNP16OV$). We apply a HP filter to population to remove small discontinuities that arise around census years.

2. Consumption growth is computed the same way as GDP, using personal consumption expenditures as the base series (PCE).

3. Investment growth is computed the same way as GDP, using gross private domestic investment as the base series ($GPDI$).

4. Government consumption growth is computed as above, using nominal government consumption (GCE) as the base series.

5. To compute transfer growth, we first construct a time series for government social transfers, using data from the Financial Accounts of the United States (flow of funds). In particular, we take the sum of social benefits ($BOGZ1FA366404005Q$), other current transfers ($BOGZ1FA366403005Q$), and subsidies ($BOGZ1FA366402005Q$). We then compute the growth rate as for GDP, by dividing the resulting series by the GDP deflator and a smoothed measure of population.

6. Wage growth is the annualized quarterly growth rate of a measure of real wages. This measure is computed by taking an index of hourly compensation for all workers in the nonfarm business sector ($COMPNFB$) and dividing it by the GDP deflator ($GDPDEF$).

7. Hours are constructed as in Del Negro et al. (2017). This is equal to average hours worked ($AWHNONAG$) times total employment ($CE16OV$), divided by the smoothed measure of

population. This series is only available from 1964Q1 onwards and so we use the Kalman filter to infer its values in the early parts of the sample.

8. The FFR is the effective federal funds rate ($FEDFUNDS$).

9. Inflation is the quarterly growth rate of the Core PCE price index, i.e. the PCE price index minus food and energy ($PCEPILFE$).

10. TFP growth is taken from the series constructed by Fernald (2012). We use non-utilization adjusted TFP and demean it for the estimation period.

11. We use 10-year CPI inflation expectations from the Survey of Professional Forecasters, downloaded from the FRB Philadelphia. We follow the procedure in Del Negro et al. (2017) and subtract 0.5 from the annualized SPF series, which is the average difference between CPI and PCE inflation over the sample. Note that this series is only available from 1979Q4 onwards; we use the Kalman filter to infer its values in the early parts of the sample.

12. The 10-year Treasury rate is the market yield on US Treasury Securities at constant maturity ($DGS10$).

13. The convenience yield is the difference between the Moody's seasoned Aaa corporate bond yield (AAA) and the 20-year Treasury rate ($DGS20$), following Krishnamurthy and Vissing-Jorgensen (2012) and Del Negro et al. (2017). This series is available from 1962Q1 to 1986Q4, and again from 1993Q4 to 2025Q2.

4.3 Special COVID-19 shocks

The estimation period, 1959Q1-2025Q2, includes the highly abnormal COVID-19 period, during which timee the US economy was subjected to unprecedented large shocks. Due to their mean-reverting nature and solution method based on first-order approximations around the steady state, it is not easy for standard DSGE and VAR models to capture these large fluctuations (Primiceri and Tambalotti, 2020).

To handle this period, we follow an approach inspired by FRB New York (2022) and Ferroni et al. (2022), and we assume that the economy was hit by a series of special i.i.d. shocks in 2020-21 that are zero in every other year. While these shocks are not active in other years, they may still have an effect post-2021 due to their impact on the endogenous state variables. We introduce special COVID-specific disturbances in three of the exogenous shocks in the model: marginal utility of consumption χ_t, the growth rate of the disutility of labor Γ_t^N,, and fiscal transfers t_t.

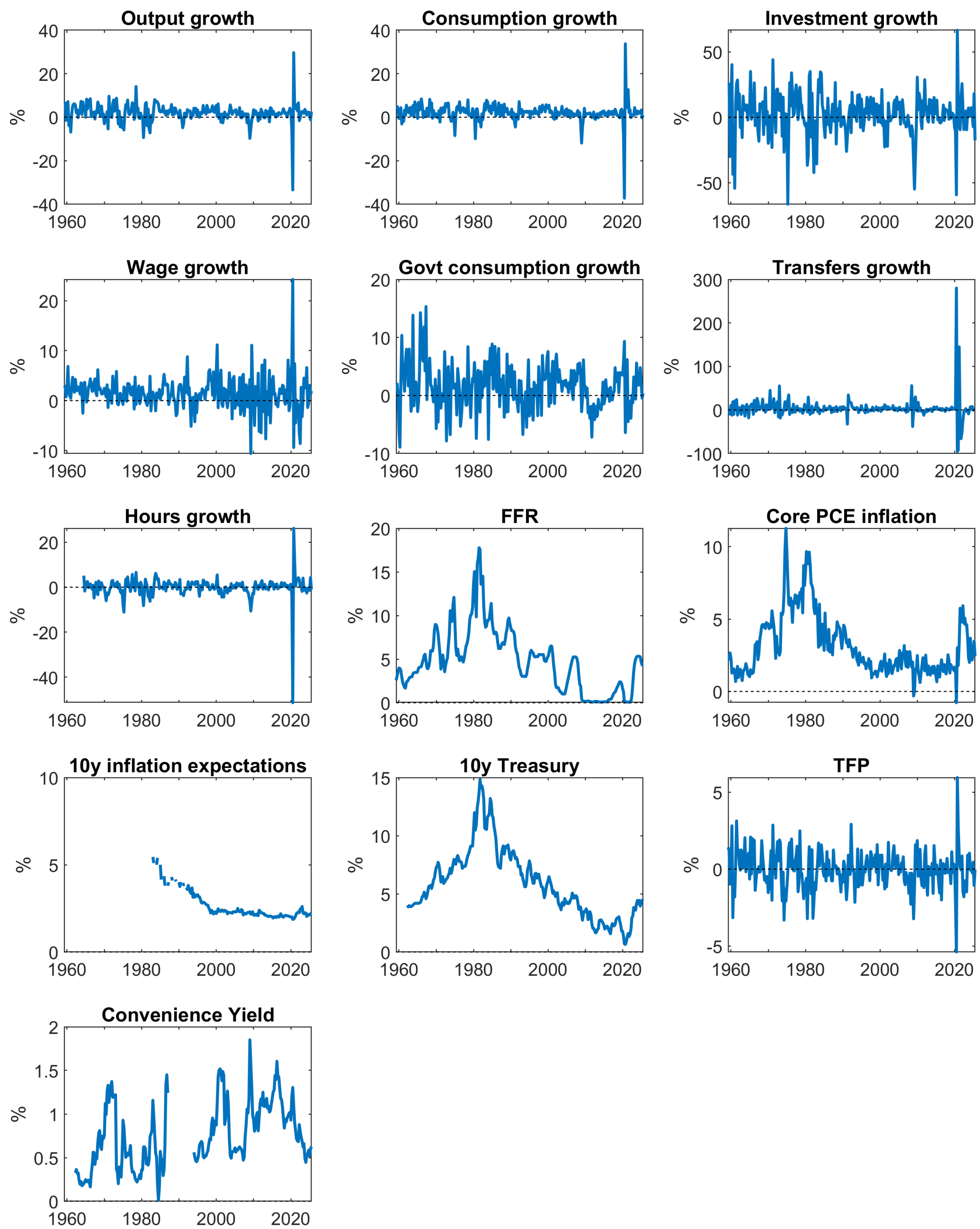

Figure 1: Time series for model observables, 1959Q1-2025Q2. See text for data sources and description.

We introduce these shocks by replacing the exogenous variables $(\chi_t, t_t, \Gamma_t^N)$ with:

$$\tilde{\chi}_t = \chi_t \times \exp(\sigma_{\chi,covid}\varepsilon_t^{\chi,covid}) \tag{87}$$

$$\tilde{t}_t = t_t \times \exp(\sigma_{t,covid}\varepsilon_t^{t,covid}) \tag{88}$$

$$\tilde{\Gamma}_t^N = \Gamma_t^N \times \exp(\sigma_{N,covid}\varepsilon_t^{N,covid}) / \exp(\sigma_{N,covid}\varepsilon_{t-1}^{N,covid}) \tag{89}$$

That is, the shocks to χ_t, t_t are one-time i.i.d. shocks, while the shocks to the disutility of labor have a MA(1) structure, since this is variable is a stochastic trend. The idea is that the realizations of the special COVID shocks $\varepsilon_t^{x,covid}$ do not affect the next period value of the exogenous variable x_{t+1} via the lagged autoregressive term. Any persistence arising from these shocks is purely due to their effect on endogenous state variables of the model. We assume that the χ shocks are active during 2020Q1-2020Q3, the t shocks during 2020Q2-2022Q1, and the Γ^N shocks during 2020Q1-2020Q4. We have experimented with these dates in order to minimize outliers in the innovations for the regular processes of these shocks. The special COVID transfer shock, for example, is active during a longer interval in order to capture the effects of the third round of transfer payments that was part of the American Rescue Plan Act of 2021.

In practical terms, we estimate these special shocks by treating them as observables with missing values during the periods in which they are active, and equal to zero in the rest of the sample. Thus the smoother infers their value as part of the estimation procedure. This procedure allows us to capture large fluctuations in 2020 and 2021 that do not necessarily affect the values of the potentially highly persistent exogenous state variables.

4.4 Calibrated Parameters

We calibrate a few parameters and estimate the rest. Table 1 summarizes the calibration. Some of these parameters are standard (e.g., depreciation rate of 2.5%), while others are set to facilitate policy experiments (e.g., the long-run inflation target of 2%). Some other parameters are not well identified from the observable data that we use, such as the persistence parameters of tax rates $\rho_{\tau,x}$. We set these to 0.9, to reflect a relatively high degree of persistence in tax rates in the US.

Finally, we exogenously calibrate the standard deviations of the special COVID-19 disturbances in order to ensure that the standard deviation of these innovations is equal to 1.

4.5 Estimation results

Model parameters. All remaining model parameters are estimated. Tables 2 and 3 summarize the prior distributions as well as the estimation results. We mostly follow Smets and Wouters (2007) in our choice of prior distributions. As in Del Negro et al. (2017) and Gelain and Lopez (2023), we impose slightly different priors for the autocorrelation coefficients of the inflation target and convenience yield shocks, on which we impose tight priors around very high persistence (0.99). This is important to capture slow-moving fluctuations in the Fed's inflation target, as well

Parameter	Description	Value	Target
δ	Depreciation rate	2.5%	Standard
μ^p	Price Markup	1.2	20% markup at steady state
μ^w	Wage Markup	1.2	20% markup at steady state
$\bar{\Pi}$	SS inflation	$1.02^{0.25}$	2% inflation target
$\bar{\tau}^d$	SS capital income tax	21.8%	Leeper et al. (2017)
$\bar{\tau}^l$	SS labor income tax	18.6%	Leeper et al. (2017)
$\rho_{\tau,x}$	Tax persistence	0.9	See text
$\bar{g}/\bar{y}$	Average govt. cons./GDP	0.202	1959-2025 average
$\bar{t}/\bar{y}$	Average transfers/GDP	0.136	1959-2025 average
$\bar{b^g}/\bar{y}$	Average govt. debt/GDP	4×0.633	1959-2025 average
$\sigma_{\chi,covid}$	SD COVID shock	0.5	See text
$\sigma_{t,covid}$	SD COVID shock	0.2	See text
$\sigma_{N,covid}$	SD COVID shock	0.01	See text

Table 1: Summary of Calibration

as to capture low frequency secular movements in real interest rates. We use a random walk Metropolis Hastings algorithm to generate 1,000,000 draws from 2 parallel Markov Chain-Monte Carlo chains. We discard the first 500,000 draws and use the following draws to approximate the posterior distribution. We tune the algorithm to achieve an acceptance rate of 20 to 30 percent.

Shocks. Figure 2 plots the estimated series for the structural shock innovations. Figure 3 plots the COVID shocks between 2019 and 2021. The model rationalizes the large fluctuations in 2020 primarily as very negative demand and labor disutility shocks. The rebound in the labor disutility shock is partly attributed to its MA(1) structure: recall that this is a growth rate shock. The model also captures large increases in government spending: the path of the transfer shock, in particular, is shaped by the three rounds of economic impact payments in 2020 and 2021.

5 Model Results

This section describes some of the model results that are treated as inputs for policy analysis. Appendix A reports the impulse response functions of selected endogenous variables to the different structural shocks.

5.1 Historical Decompositions

One of the advantages of using a structural model is that by giving a structural interpretation to the shocks, it allows researchers and policymakers to perform historical decompositions that describe the relative contribution of the different exogenous variables to observed movements in endogenous variables of interest. Figure 4 present simplified historical shock decompositions for

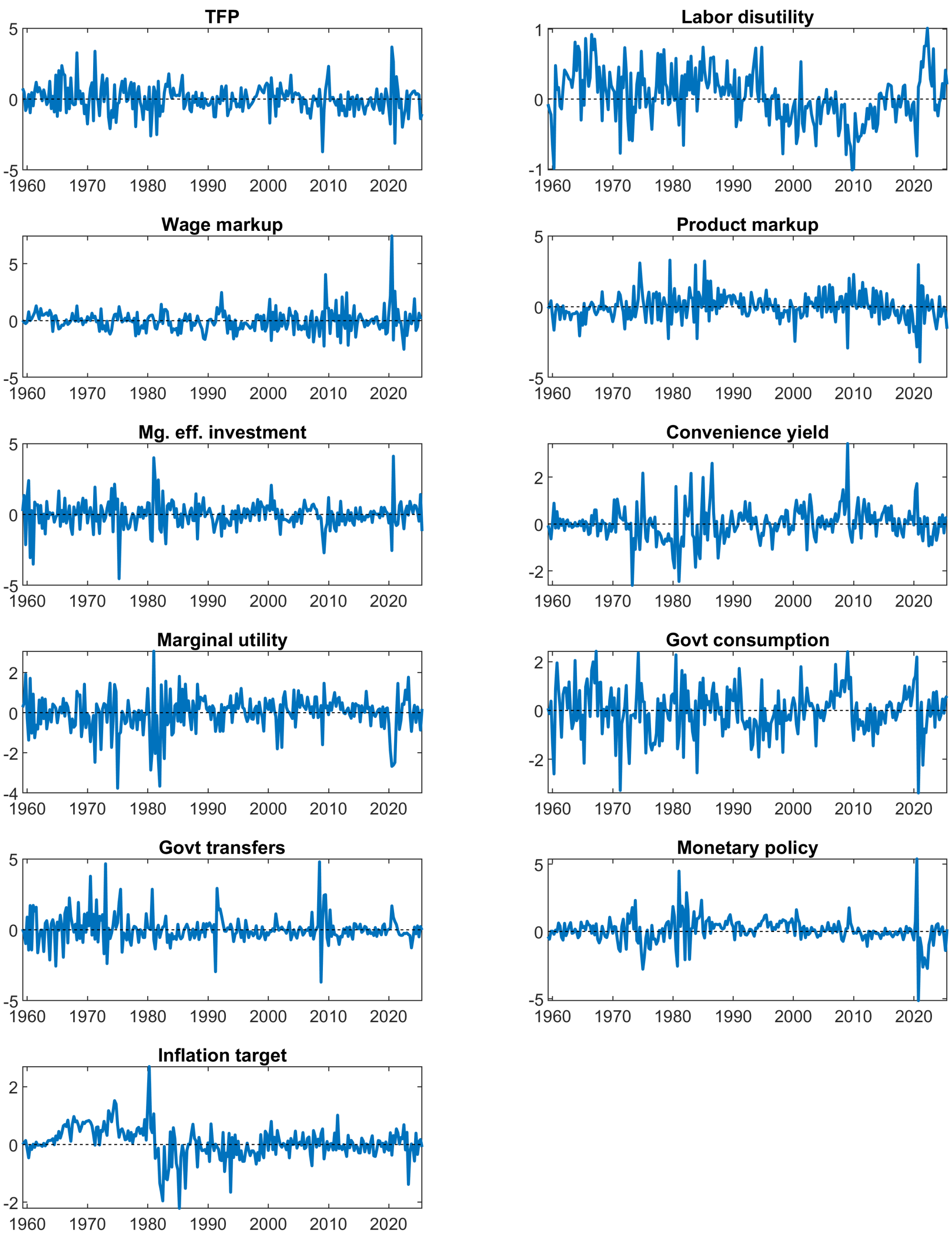

Figure 2: Time series for estimated model shocks, 1959Q1-2024Q4. The vertical dashed line corresponds to 2019Q4, the last period of estimation.

Parameter	Description	Prior distr.	Prior mean	Prior SD	Post. mean	Post. 10%	Post. 90%
Γ^Z	TFP growth	N	1.004	0.005	1.0050	1.0044	1.0057
Γ^N	Labor disutil. growth	N	1.000	0.005	0.9997	0.9996	0.9997
$100\left(\frac{1}{\beta}-1\right)$	Discount factor	IG	0.040	0.020	0.0451	0.0188	0.0744
φ	Inverse Frisch	G	2.000	0.750	0.8103	0.4428	1.1849
η_p	Product menu cost	G	80.000	10.000	93.5342	77.6806	109.3574
η_w	Wage menu cost	G	80.000	10.000	84.1123	68.6630	98.6999
ψ_i	Inv. adj. costs	IG	5.000	5.000	1.3816	1.0450	1.7048
ι_Π	Product indexation	B	0.500	0.150	0.0674	0.0226	0.1108
ι_w	Wage indexation	B	0.500	0.150	0.6974	0.5158	0.8833
σ_a	Utilization costs	IG	0.500	0.100	0.4504	0.3213	0.5687
α	Capital share	N	0.300	0.050	0.1957	0.1862	0.2054
ψ_w	Portfolio adj. costs	IG	0.500	0.250	0.1746	0.1366	0.2101
λ	Share of workers	B	0.700	0.100	0.7281	0.6032	0.8569
$\bar{\vartheta}$	Convenience yield	N	1.003	0.001	1.0016	1.0009	1.0023
$\bar{tp}$	Term premium	IG	0.013	0.010	0.0101	0.0054	0.0147
ϕ_Π	Taylor rule	N	2.000	0.500	3.1398	2.7118	3.5395
ϕ_Y	Taylor rule	N	0.250	0.250	0.9093	0.6809	1.1521
ρ_r	Taylor rule	B	0.700	0.200	0.8193	0.7914	0.8484
$\frac{\bar{b}^w}{\bar{y}}$	Worker portfolio	N	0.000	0.500	0.8367	0.3904	1.2695
$\phi_{\tau,l}$	Labor tax response	IG	0.100	0.100	0.0494	0.0289	0.0691
$\phi_{\tau,d}$	Capital tax response	IG	0.100	0.100	0.0688	0.0325	0.1053

Table 2: Prior and posterior distributions for estimated structural parameters. B = beta, G = gamma, N = normal, IG = inverse gamma.

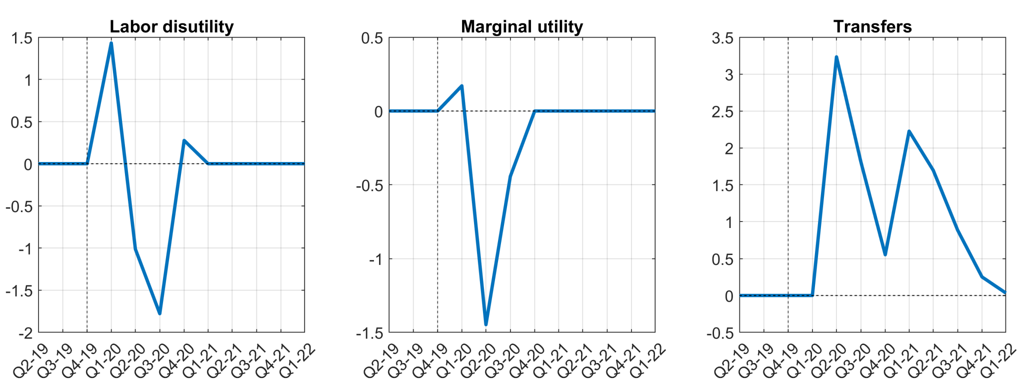

Figure 3: Time series estimated for COVID shocks, 2019Q3-2022Q2. The vertical dashed line corresponds to 2019Q4. See text for details.

Parameter	Description	Prior distr.	Prior mean	Prior SD	Post. mean	Post. 10%	Post. 90%
ρ_{Γ^Z}	AR TFP growth	B	0.500	0.200	0.0754	0.0197	0.1277
ρ_{μ^p}	AR price markup	B	0.500	0.200	0.7207	0.6415	0.7979
ρ_{μ^w}	AR wage markup	B	0.500	0.200	0.1028	0.0268	0.1756
ρ_{ζ}	AR MEI	B	0.500	0.200	0.3371	0.1954	0.4757
ρ_{χ}	AR mg. util.	B	0.500	0.200	0.9463	0.9305	0.9620
ρ_{cy}	AR conv. yield	B	0.990	0.005	0.9552	0.9443	0.9664
ρ_G	AR govt.	B	0.500	0.200	0.9657	0.9484	0.9834
ρ_T	AR transfers	B	0.500	0.200	0.9920	0.9849	0.9991
ρ_{Π}	AR infl. target	B	0.990	0.005	0.9936	0.9897	0.9979
ρ_{mp}	AR mon. pol.	B	0.500	0.200	0.0927	0.0264	0.1559
ρ_{Γ^N}	AR labor disutil.	B	0.500	0.200	0.3017	0.0855	0.5049
σ_{Γ^Z}	SD TFP growth	IG	0.010	0.050	0.0079	0.0073	0.0084
σ_{μ^p}	SD price markup	IG	0.010	0.050	0.0219	0.0176	0.0263
σ_{μ^w}	SD wage markup	IG	0.010	0.050	0.1782	0.1416	0.2134
σ_{ζ}	SD MEI	IG	0.010	0.050	0.0502	0.0374	0.0618
σ_{χ}	SD mg. util.	IG	0.010	0.050	0.0262	0.0206	0.0319
σ_{cy}	SD conv. yield	IG	0.005	0.050	0.0011	0.0008	0.0013
σ_G	SD govt.	IG	0.010	0.050	0.0095	0.0086	0.0102
σ_T	SD transfers	IG	0.010	0.050	0.0264	0.0244	0.0283
σ_{Π}	SD infl. target	IG	0.001	0.050	0.0004	0.0003	0.0005
σ_{mp}	SD mon. pol.	IG	0.010	0.050	0.0025	0.0023	0.0028
σ_{Γ^N}	SD labor disutil.	IG	0.010	0.050	0.0028	0.0020	0.0035
$\rho_{me,tfp}$	ME TFP	B	0.500	0.200	0.0980	0.0260	0.1647
$\sigma_{me,tfp}$	ME TFP	IG	0.010	0.050	0.0102	0.0094	0.0110
$\rho_{me,cy}$	ME conv. yield	B	0.500	0.200	0.9380	0.8987	0.9784
$\sigma_{me,cy}$	ME conv. yield	IG	0.010	0.050	0.0014	0.0012	0.0015
$\rho_{me,gdp}$	ME GDP	B	0.500	0.200	0.0838	0.0191	0.1458
$\sigma_{me,gdp}$	ME GDP	IG	0.010	0.050	0.0030	0.0027	0.0032
$\rho_{me,inflexp}$	ME infl. exp.	B	0.500	0.200	0.7845	0.5974	0.9797
$\sigma_{me,inflexp}$	ME infl. exp.	IG	0.010	0.050	0.0016	0.0014	0.0019
$\rho_{me,tp}$	ME term prem.	B	0.500	0.200	0.9587	0.9368	0.9813
$\sigma_{me,tp}$	ME term prem.	IG	0.010	0.050	0.0035	0.0032	0.0039

Table 3: Prior and posterior distributions for estimated shock parameters. B = beta, G = gamma, N = normal, IG = inverse gamma.

year-over-year core PCE inflation, quarter-over-quarter core PCE inflation, the output gap, and the spot natural rate of interest. In these simplified decompositions, we group shocks into the aforementioned groups: demand, supply, fiscal, and monetary. Figure 7 in Appendix B presents the full decomposition.

The model decomposition attributes a significant role to monetary and fiscal policy in driving the recent inflationary episode. Fiscal support in the form of transfers triggered a significant demand expansion, while monetary policy kept interest rates below what was warranted by the Taylor rule estimated on historical data. The dominant component of the monetary group of shocks is the inflation target, which the model estimates as being higher than usual during this period. This should not be literally interpreted as an inflation target above 2%, but rather as a way for a linearized model to rationalize a higher tolerance for deviations of inflation from its target.[2] The estimates for these series mostly reflected elevated long-term inflation expectations during this period. These fiscal and monetary impulses were responsible for closing the output gap and maintaining output above its flexible price level since early 2021.

As of 2025Q2, the model identifies fiscal pressures on inflation as having disappeared. Rising supply pressures as well as elevated long-term inflation expectations have contributed to keeping inflation above the 2% target. YoY inflation is significantly affected by base effects, and so it is also instructive to look at the behavior of quarter-over-quarter inflation, in panel (b). This figure reveals that the effect of demand factors on inflation is negative.

5.2 Model Forecasts

Figure 5 presents unconditional model forecasts through 2030Q4, using available data as of 2025Q2. These forecasts are generated by simulating the model forward, and take into account uncertainty emanating from the innovations to the exogenous variables. The shaded areas correspond to a 68% confidence interval.

Table 4 presents point estimates for a few variables of interest, from 2024 to 2028, including the long-run that corresponds to the model's steady state. Output growth and core PCE inflation refer to annual Q4/Q4 rates, while the point estimates for all other variables refer to their levels as of Q4 of the respective year. Note that the numbers in this table refer to aggregate output growth, not per capita output growth that is used as the model observable.

5.3 Natural rate of interest

The model produces estimates for the natural rate of interest that are in line with those in the literature. Model estimates for r^* tend to be more volatile and lower in terms of their level than standard estimates. Figure 6 compares the 5-year forward implied natural rate that is estimated in the model to some of the most widely reported measures of the natural rate: those of Holston et al.

[2] In a fully nonlinear model, this could be captured via a time-varying Taylor rule parameter ϕ_Π, but fluctuations in this parameter are second-order and therefore vanish due to linearization.

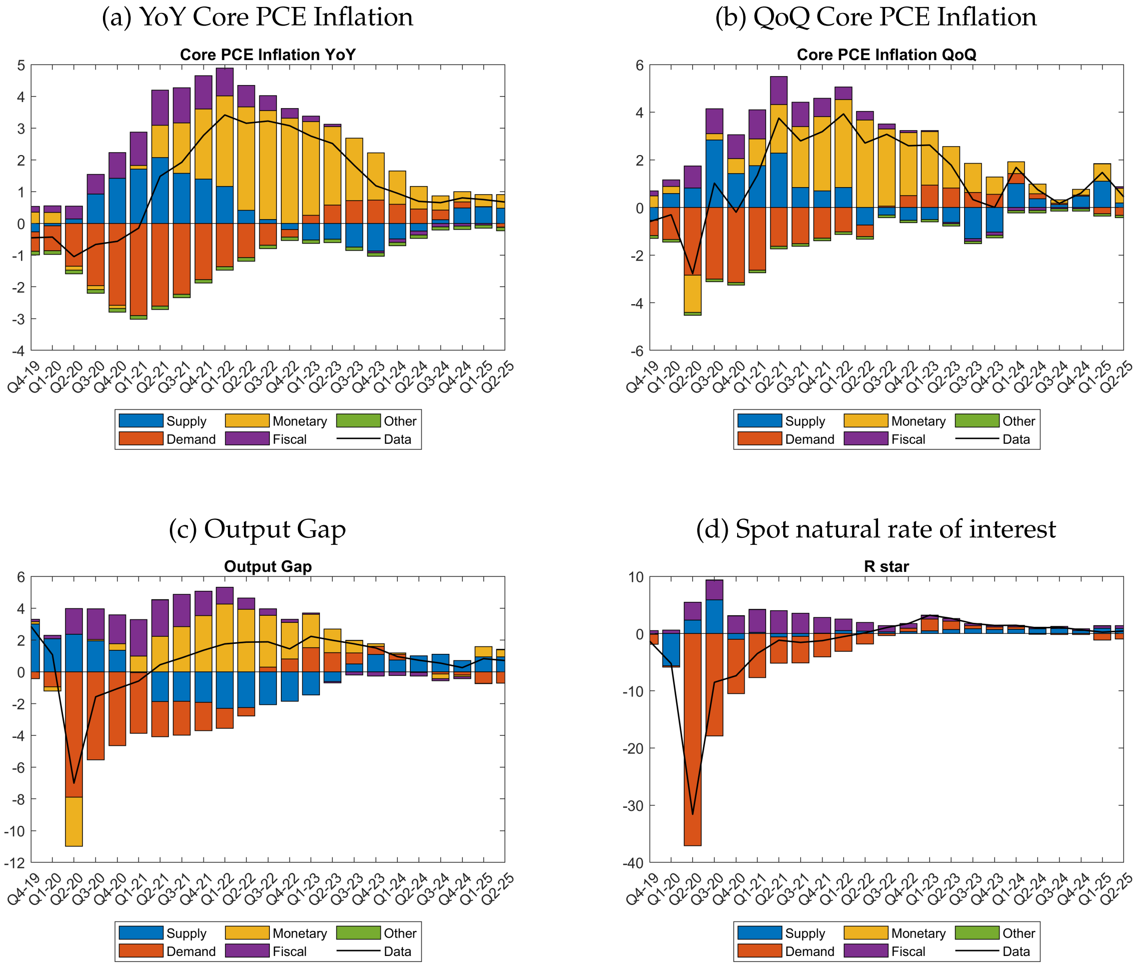

Figure 4: Simplifed historical decompositions 2019Q4-2024Q4, relative to steady state value of the variable. Other includes initial conditions and measurement error.

	Output growth	Core PCE inflation	Federal funds rate	Natural rate	Output gap
2025	1.2%	2.8%	4.1%	1.4%	-0.1%
2026	1.7%	2.6%	4.0%	1.2%	-1.1%
2027	2.5%	2.2%	3.8%	1.2%	-1.3%
2028	2.8%	2.1%	3.7%	1.2%	-1.1%
2029	2.9%	2.1%	3.7%	1.2%	-0.9%
2030	2.8%	2.2%	3.7%	1.3%	-0.8%
Long-run	2.6%	2.0%	3.5%	1.4%	0.0%

Table 4: Model forecasts: point estimates. Output growth refers to aggregate (not per capita) output growth. Output growth and inflation are Q4/Q4, all other variables are Q4.

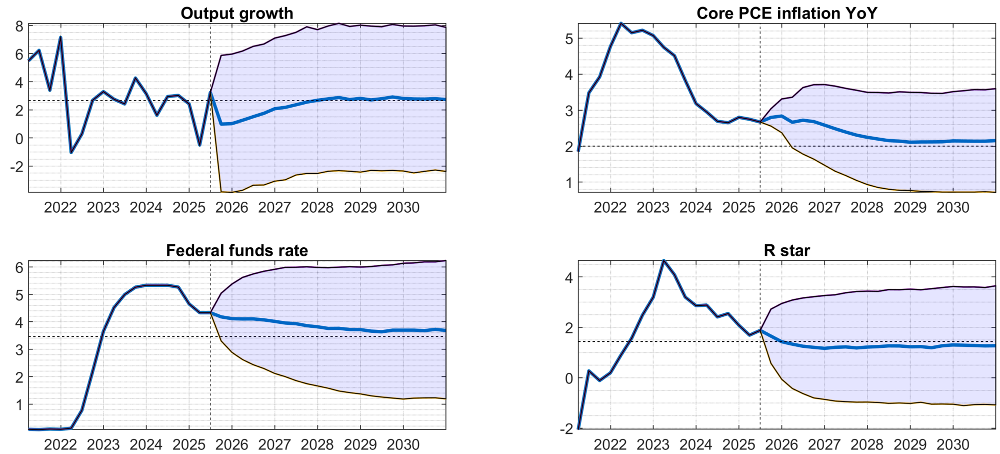

Figure 5: Unconditional model forecasts. The vertical dashed line is 2024Q2, the last quarter of observable data. Shaded areas correspond to 68% confidence intervals.

	Holston-Laubach-Williams	Lubik-Matthes (median)
Spot rate, r_t^*	0.43	0.66
1y forward, $\mathbb{E}_t r_{t+4}^*$	0.69	0.70
5y forward, $\mathbb{E}_t r_{t+20}^*$	0.81	0.49
10y forward, $\mathbb{E}_t r_{t+40}^*$	0.79	0.25

Table 5: Correlations between model r^* and standard measures

(2023), based on Laubach and Williams (2003), and the median estimate of Lubik and Matthes (2015). The DSGE-based measure displays fluctuations that are broadly in line with the other measures, experiencing a decreasing trend that seems to have stabilized around the post-Great Financial Crisis period. After this stabilization during the 2015-20 period, it fell again with the onset of the COVID-19 pandemic and associated economic disturbances. More recently, it has risen considerably to around 1.5%, the first time that it reaches this level since the mid 2000s. These recent movements are particularly consistent with the Lubik-Matthes measure, which also implies a recent increase in the estimated natural rate of interest.

Table 5 presents correlations between these measures and model-based objects: the spot rate, and the 1, 5, and 10-year forward natural rates. The table shows that the model-based r^* tends to be more correlated with LM at shorter horizons, and presents a higher correlation with HLW at longer horizons. Interpreted through the lens of the model, this suggests that the LM measure is perhaps better able to capture higher frequency movements in the natural rate, while the HLW measures place more weight on longer-term trends. Remarkably, the correlations between the different model measures and these external measures tend to be higher than the correlations between those external measures themselves.

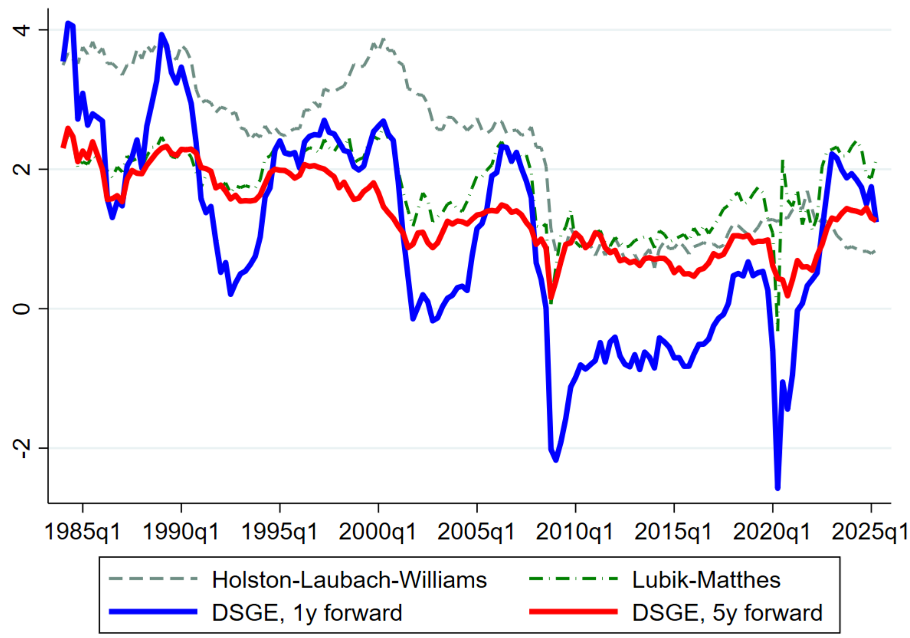

Figure 6: Standard measures of r^* versus model-implied $\mathbb{E}_t r^f_{t+4}$ and $\mathbb{E}_t r^f_{t+20}$. Sources: FRB New York and FRB Richmond.

6 Conclusion

This document serves as a technical description of the DSGE model that is used as one of several inputs for forecasting and policy analysis at the St. Louis Fed. The present DSGE model extends a medium-scale New Keynesian DSGE model to allow for limited type of household heterogeneity and an explicit fiscal sector, which accounts for heterogeneous marginal propensities to consume and a role for fiscal policies such as social transfers.

These model extensions fall within the scope of standard methodological approaches to DSGE modeling, which allows us to leverage existing toolkits to easily solve and estimate the model to match US data. The model can easily be extended along several dimensions that may allow the analysis of different phenomena and sectors of the US economy. It is possible to add a financial accelerator along the lines of FRB New York (2022) or a frictional labor market that explicitly accounts for unemployment and vacancy rates as in Arias et al. (2019) or Gelain and Lopez (2023). Another natural direction is to include an explicit financial intermediation sector as in Gertler and Karadi (2011), which would allow financial factors to play a larger role in explaining macroeconomic fluctuations.

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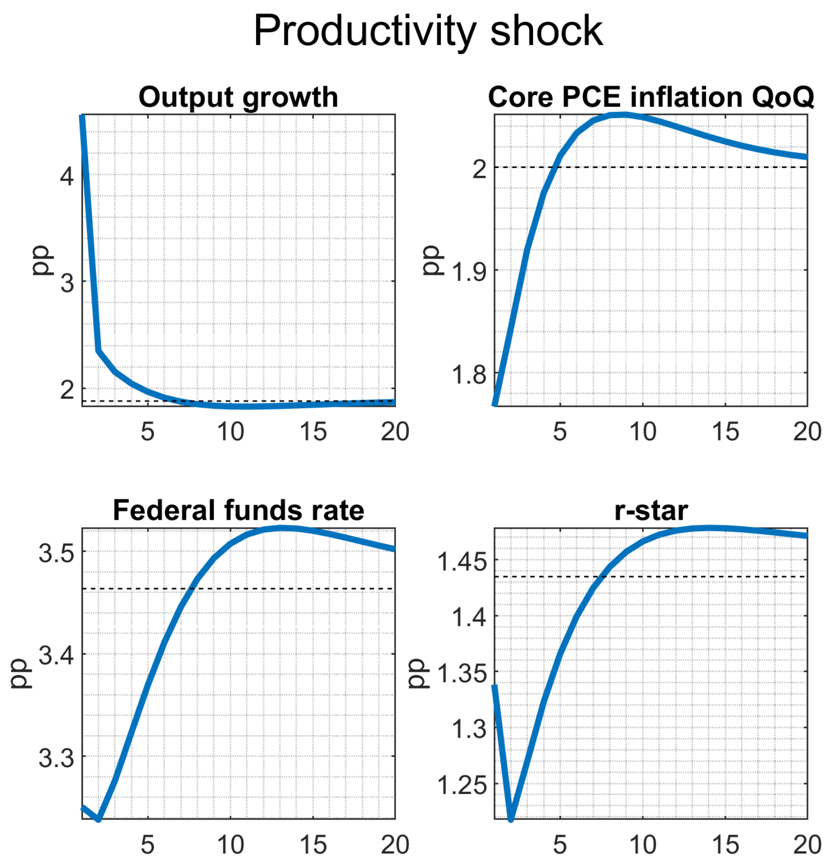
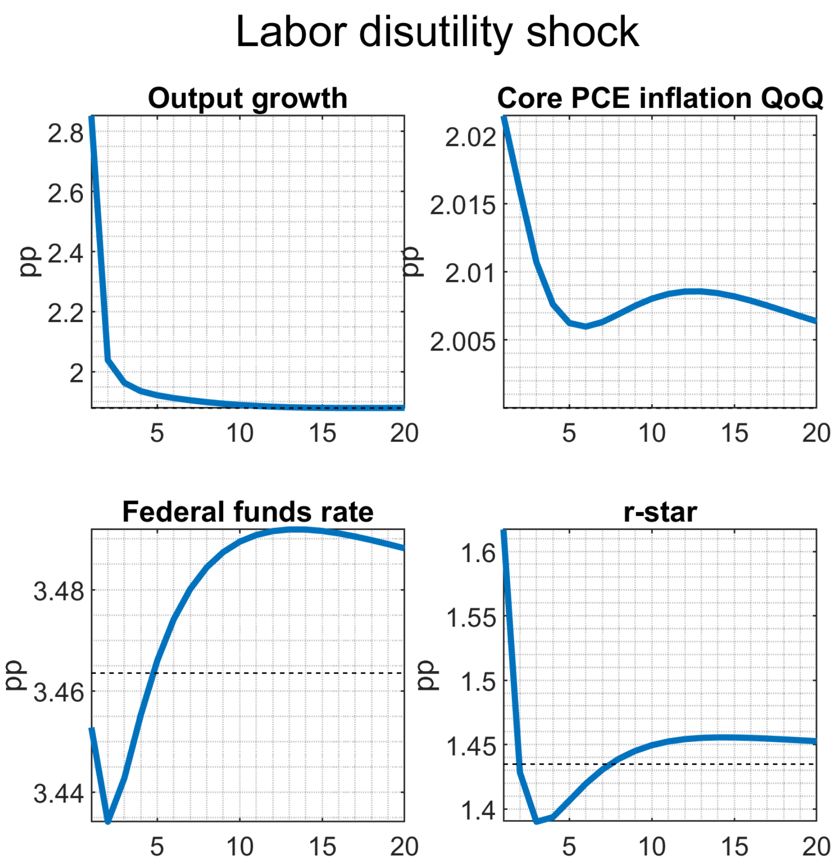
A Impulse response functions to structural shocks

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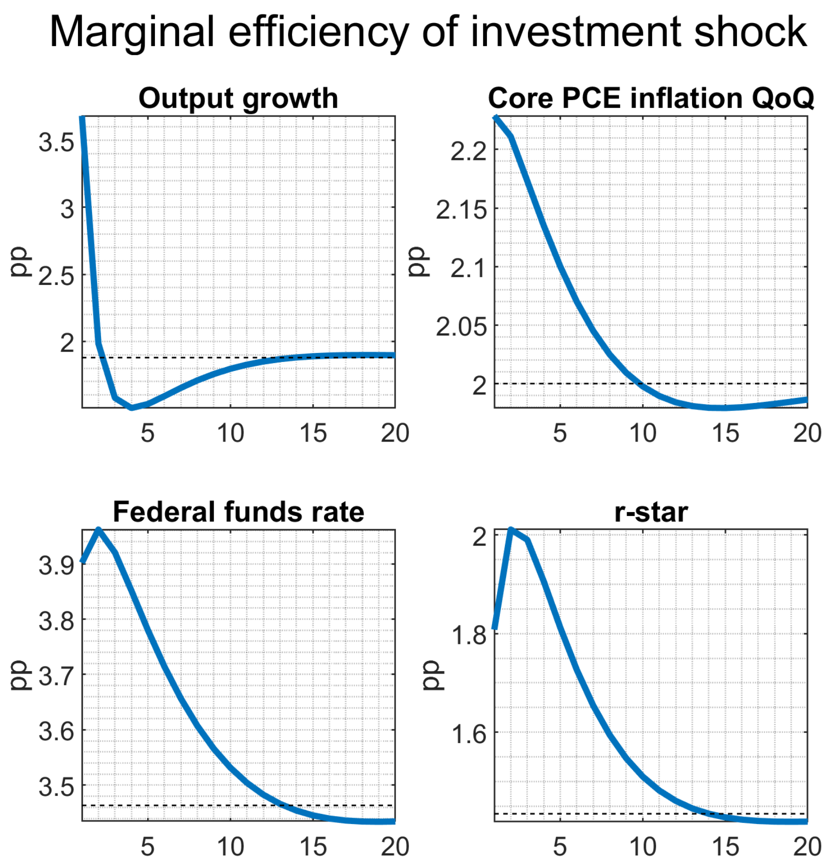
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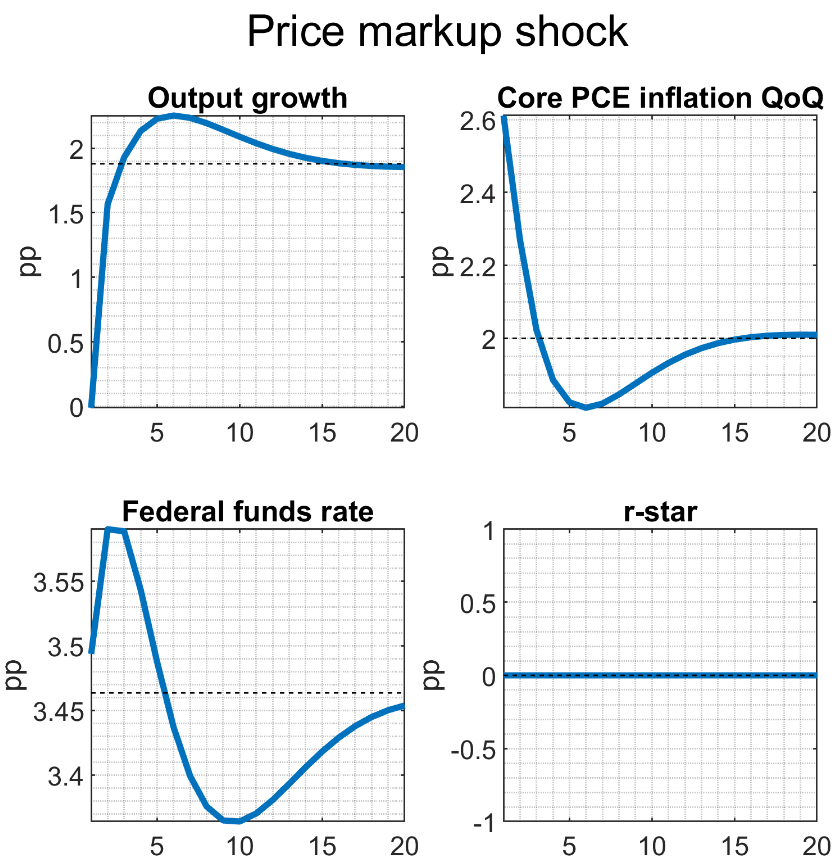
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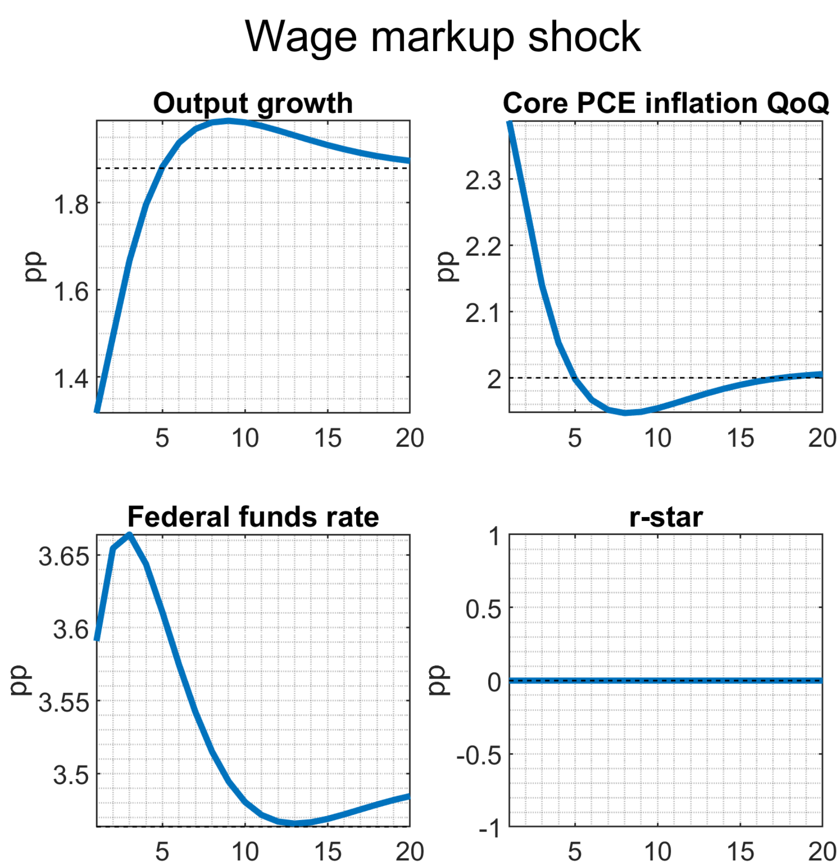
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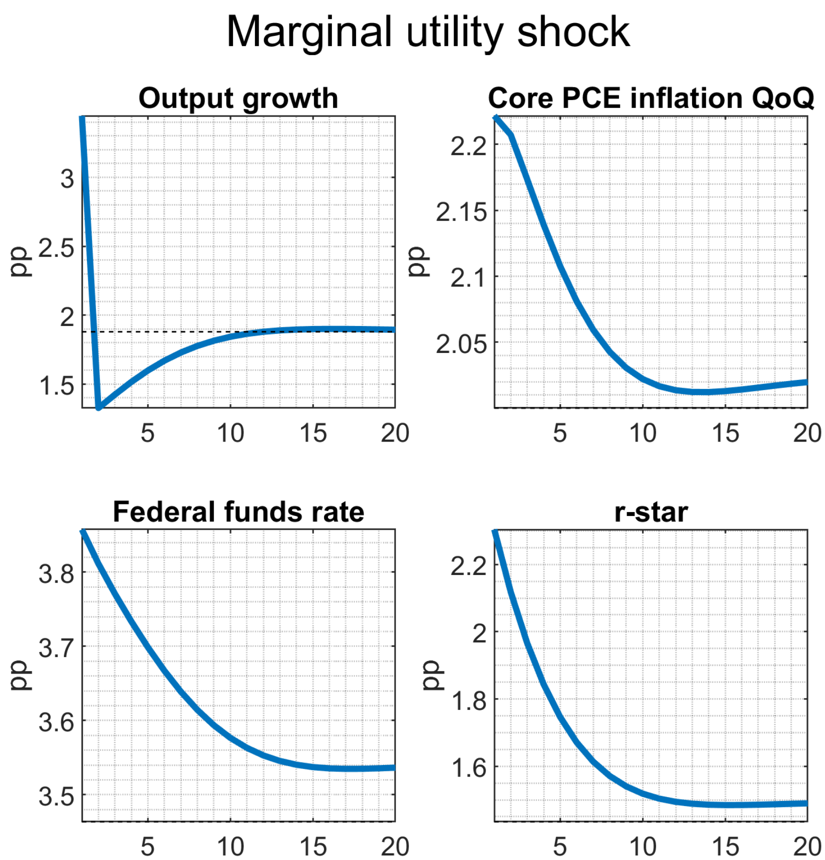
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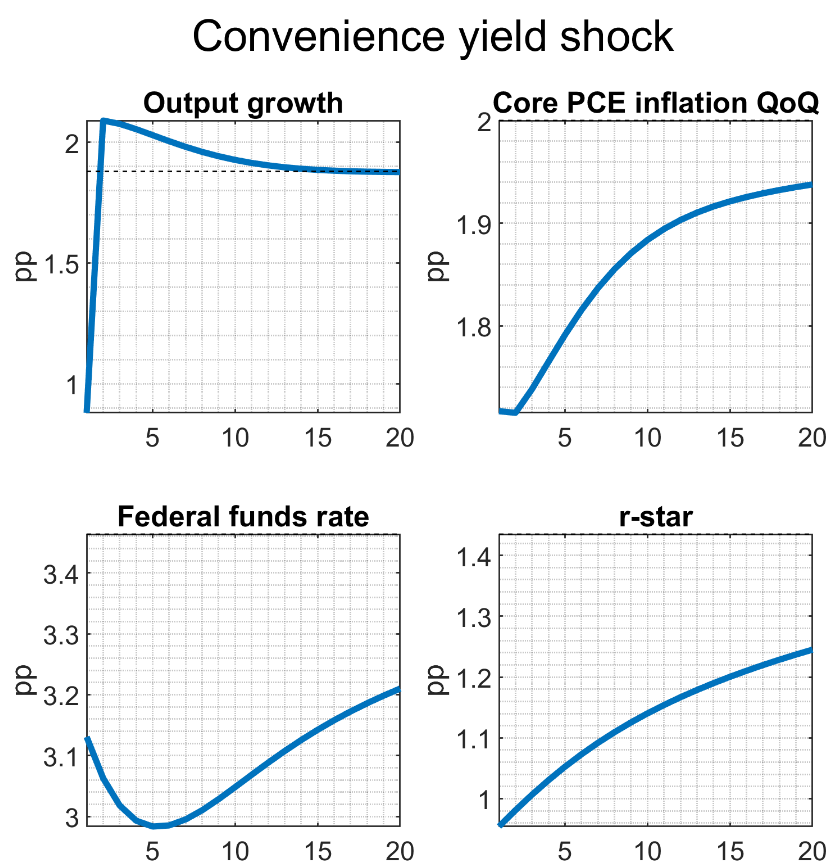
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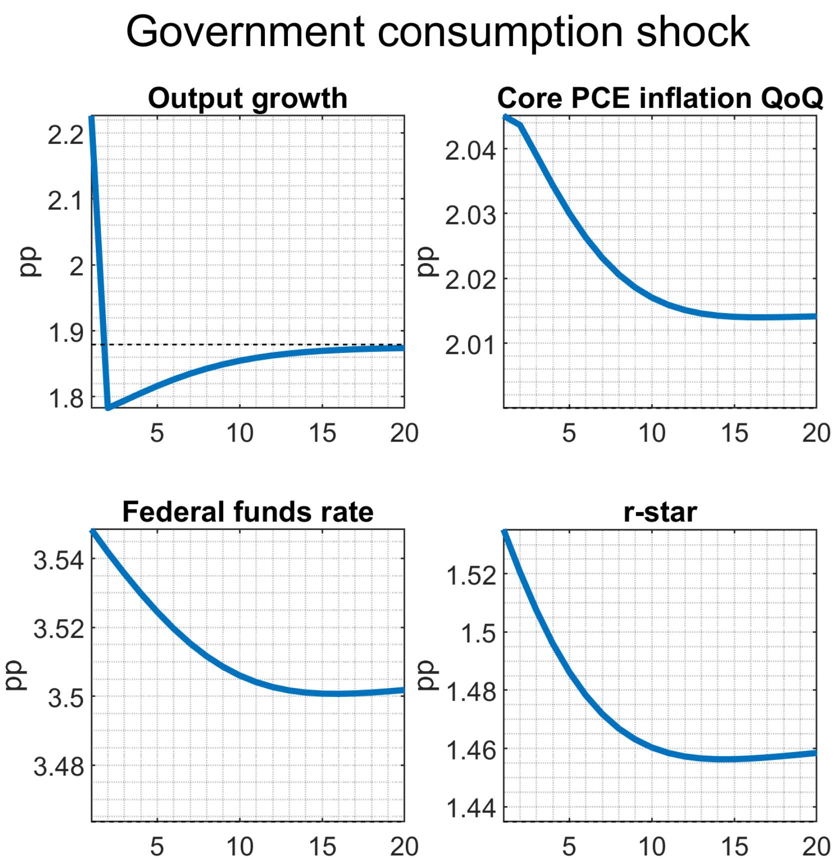
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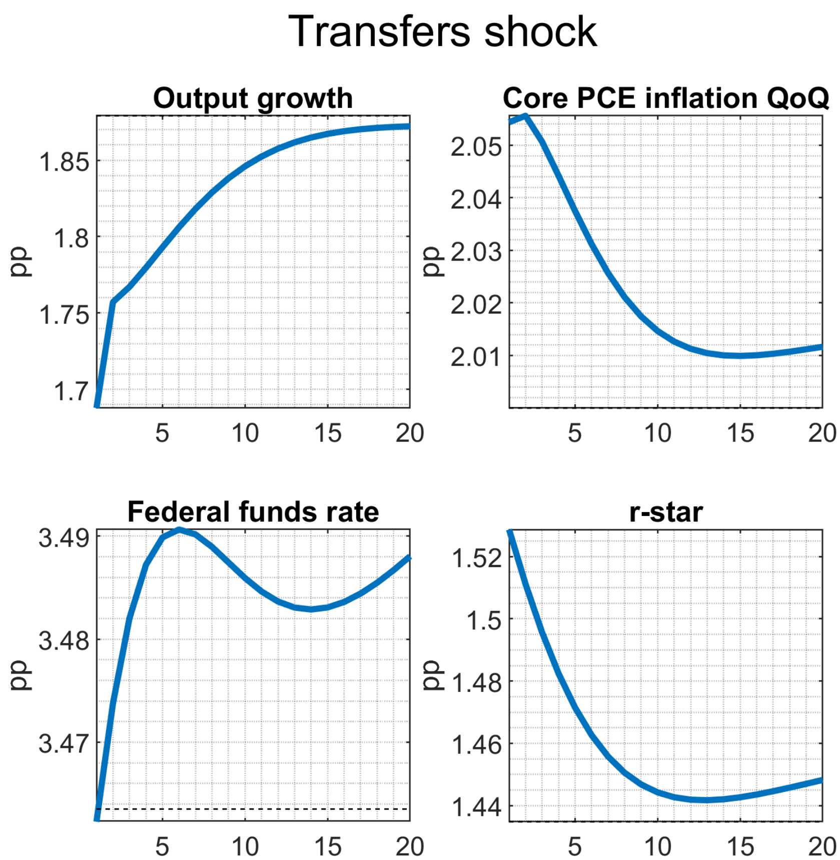
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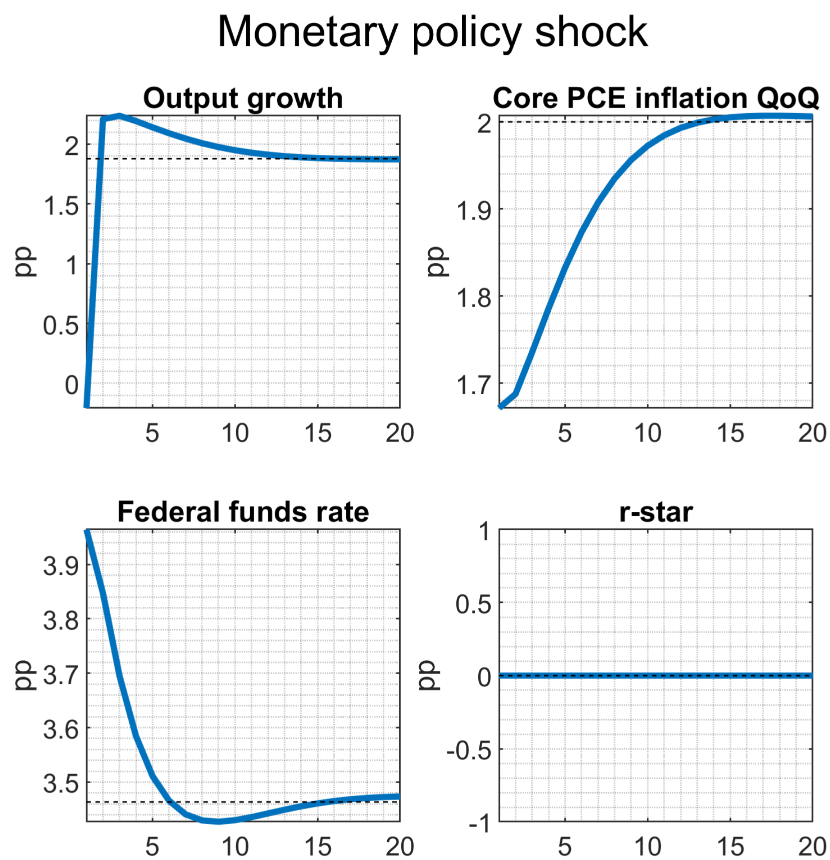
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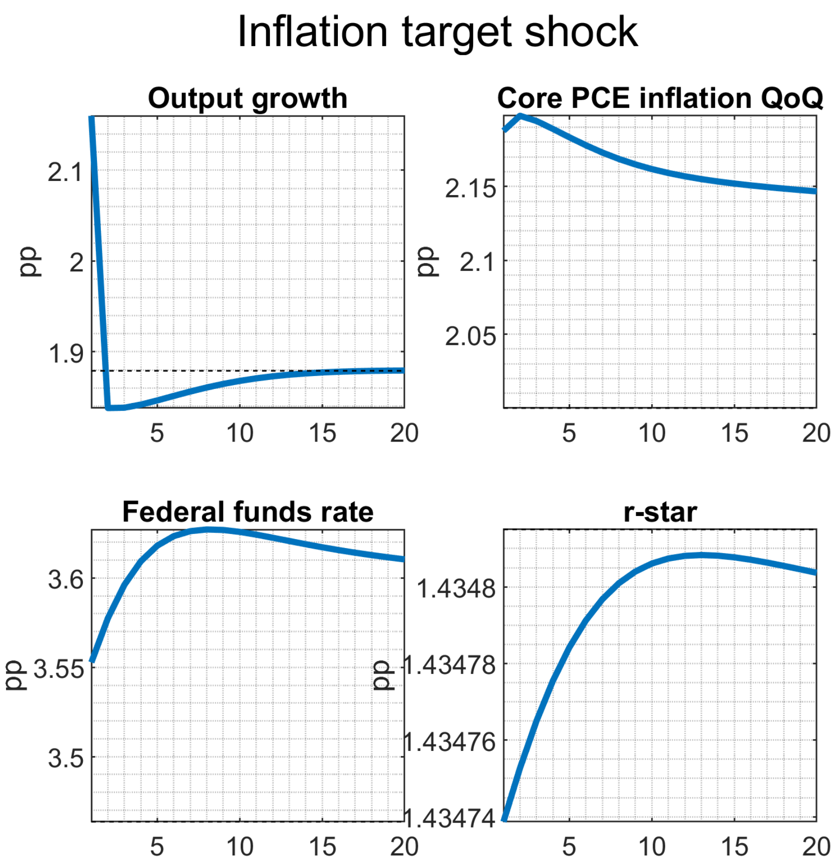
-0.5
-1



Inflation target shock
Output growth
2.1
2
1.9
pp
5
10
15
20
Core PCE inflation QoQ
2.15
2.1
2.05
pp
5
10
15
20
Federal funds rate
3.6
3.55
3.5
pp
5
10
15
20
r-star
1.4348
1.43478
1.43476
1.43474
pp
5
10
15
20

B Detailed Historical Decompositions

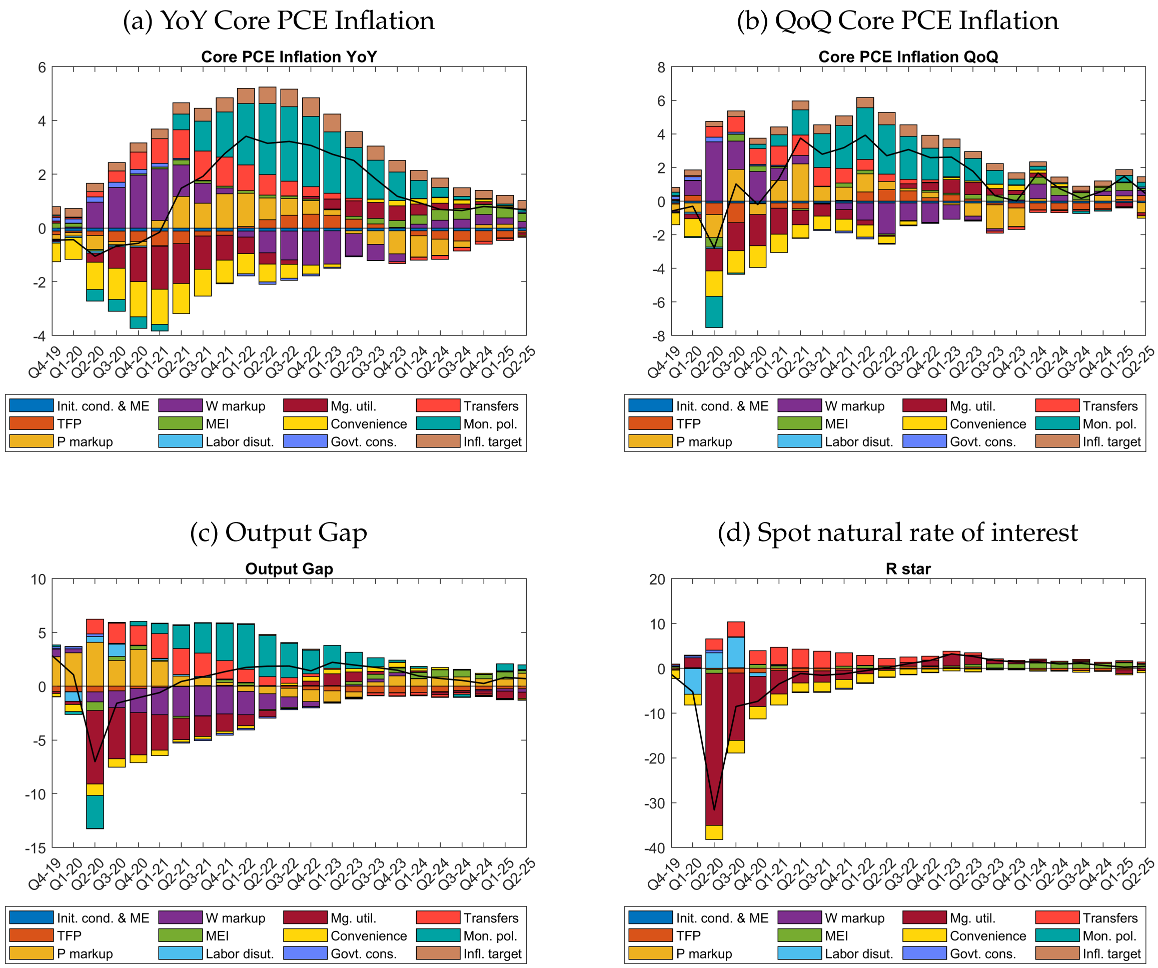


Figure 7: Detailed historical decompositions 2019Q4-2024Q4, relative to steady state value of the variable. Other includes initial conditions and measurement error.