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Appendix A. Facts: Robustness and Extensions

This appendix shows that the key facts described in section 3 are robust to many obvious deviations from the baseline setup. To conduct these robustness checks and extensions we add variables to the baseline VAR, which in some case also results in shorter samples. Therefore, we perform these checks using the conditional forecasts introduced in section 3.1, since this technique typically leads to narrower posterior credible sets and sharper inference.

More measures of price inflation. The first robustness check consists of extending the baseline VAR specification to include three additional inflation measures, based on the Consumer Price Index (CPI), core CPI and the headline PCE price index. Figure A.1 shows that the attenuation in the response of these measures of inflation in the second sample is similar to that of the two inflation variables included in the baseline model. We conclude that the marked decrease in the association of price inflation to labor market slack does not depend on how we measure goods prices.

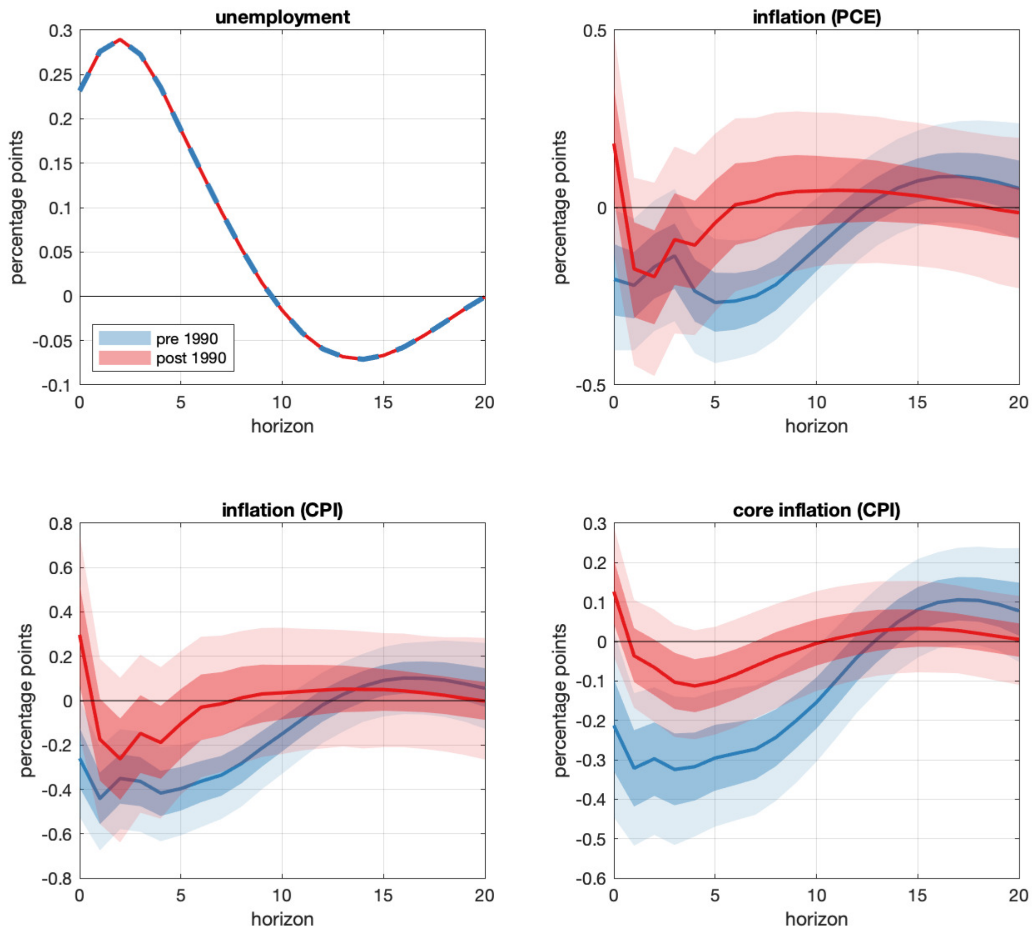

FIGURE A.1. Responses of alternative measures of price inflation, conditional on unemployment following the path in the first subplot. These responses are computed by applying the methodology described in section 3.1 to the baseline VAR of section 2.2, augmented with data on PCE, CPI and core CPI inflation. The solid lines are posterior medians, while the shaded areas correspond to 68- and 95-percent posterior credible regions. The pre- and post-1990 samples consist of data from 1964:II to 1989:IV, and from 1989:I to 2019:III, respectively.

More wage measures. Measuring wages and especially their cyclicality is notoriously difficult. For example, standard wage series like those used in the baseline VAR do not account for changes in the mix of workers over the business cycle, which makes them appear less cyclical (e.g. Solon et al., 1994). A better wage indicator in this respect is the employment cost index (ECI), which focuses on pay rates for specific types of work, thus controlling for these composition effects. These data, however, are only available since 1980 (or 1975, but without seasonal adjustment). Therefore, using them in the first sample is

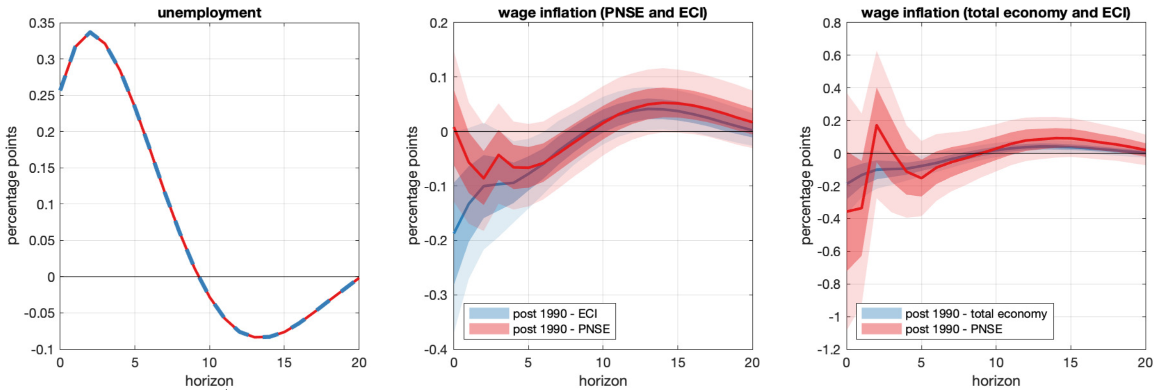

FIGURE A.2. Responses of alternative measures of wage inflation, conditional on unemployment following the path in the first subplot. These responses are computed by applying the methodology described in section 3.1 to the baseline VAR of section 2.2, augmented with the annualized quarterly growth rate of the employment cost index (wages and salaries of all workers in private industries). The solid lines are posterior medians, while the shaded areas correspond to 68- and 95-percent posterior credible regions. The pre- and post-1990 samples consist of data from 1964:II to 1989:IV, and from 1989:I to 2019:III, respectively.

problematic. But we can add a wage inflation measure from the ECI (wages and salaries of all workers in private industries) to the VAR in the second sample. Figure A.2 compares the response of the ECI wage measure to the ones in the baseline VAR. As expected, the ECI is more clearly cyclical than the other wage measures, falling by a larger amount than the PNSE on impact. Moreover, its response is much more sharply estimated than that of the wage measure for the total economy, confirming that nominal wages remain sensitive to business cycle shocks after 1990.

Figure A.3 presents another interesting piece of evidence on the behavior of wages. It compares the conditional forecasts of wage inflation, as measured by the ECI, when the VAR is estimated with and without data after 2007. The purpose of this exercise is to verify the extent to which the Great Recession and the subsequent period of slow recovery might have impacted wage dynamics. In particular, one hypothesis often mentioned to explain the missing disinflation over the Great Recession is that downward nominal wage rigidity might have limited the fall in wages, and hence in costs and inflation. The conditional forecasts in the figure suggest that this factor is unlikely to be a major driver of the reduced cyclical sensitivity of inflation since 1990, given that the dynamics of wage inflation are similar regardless of whether we include post-2007 data.

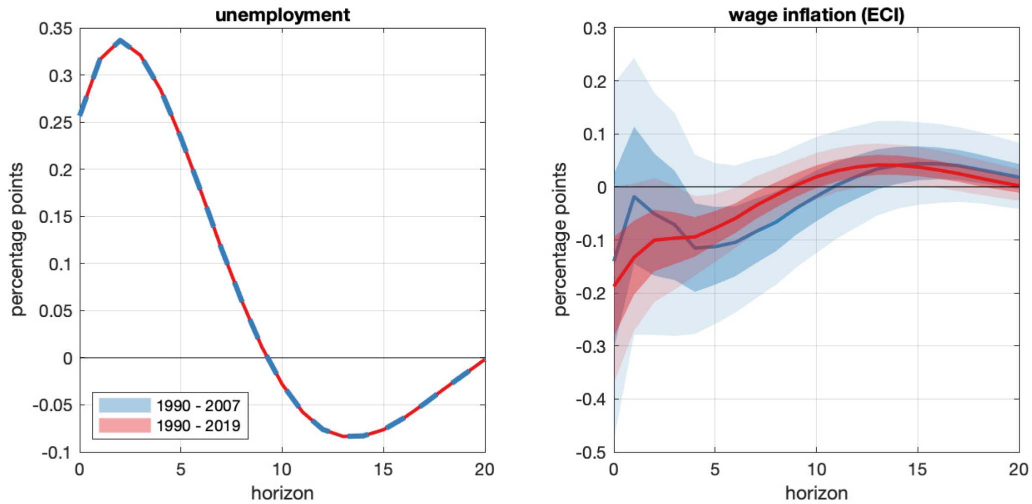

FIGURE A.3. Responses of alternative measures of wage inflation, conditional on unemployment following the path in the first subplot. These responses are computed by applying the methodology described in section 3.1 to the baseline VAR of section 2.2, augmented with the annualized quarterly growth rate of the employment cost index (wages and salaries of all workers in private industries). The solid lines are posterior medians, while the shaded areas correspond to 68- and 95-percent posterior credible regions. The 1990-2007 and 1990-2019 samples consist of data from 1989:I to 2007:IV and from from 1989:I to 2019:III, respectively.

More measures of the labor share. To further probe the stability of the business cycle correlation between unemployment and unit labor costs, we also extend the baseline VAR to include two additional commonly used measures of the labor share. These are the logarithm of the labor share in the nonfarm business sector (NFBS) and in the nonfinancial corporate sector (NFCS), from the productivity and costs release. Figure A.4 plots the behavior of these two variables, which is similar to that of the labor share in the total economy included in the baseline VAR.

More measures of employment and real activity. We now augment the baseline VAR with the logarithm of the employment-to-population ratio and of the ratio between GDP and the CBO estimate of potential GDP. Figure A.5 illustrates that the responses of these additional variables are almost exactly the same in the two samples, confirming the results based on hours and GDP of the previous subsections.

Alternative ways of splitting the sample. As mentioned in section 2.2, there are at least two other dates in which we could have reasonably split the sample: 1984—right after the Volcker disinflation—and 1994—when inflation was more clearly stabilized around 2%. Figures A.6 and A.7 show that splitting the sample at these two alternative dates has little

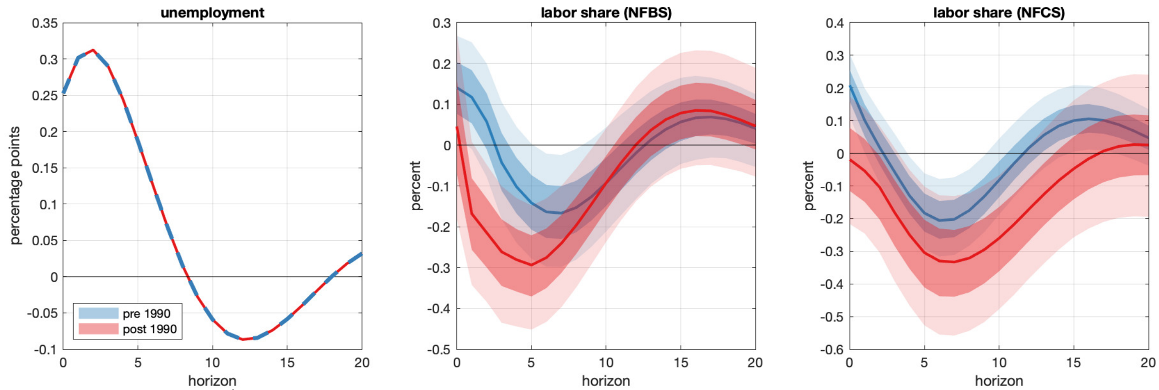

FIGURE A.4. Responses of alternative measures of the labor share, conditional on unemployment following the path in the first subplot. These responses are computed by applying the methodology described in section 3.1 to the baseline VAR of section 2.2, augmented with the logarithm of the labor share in the nonfarm business sector and in the nonfinancial corporate sector. The solid lines are posterior medians, while the shaded areas correspond to 68- and 95-percent posterior credible regions. The pre- and post-1990 samples consist of data from 1964:II to 1989:IV, and from 1989:I to 2019:III, respectively.

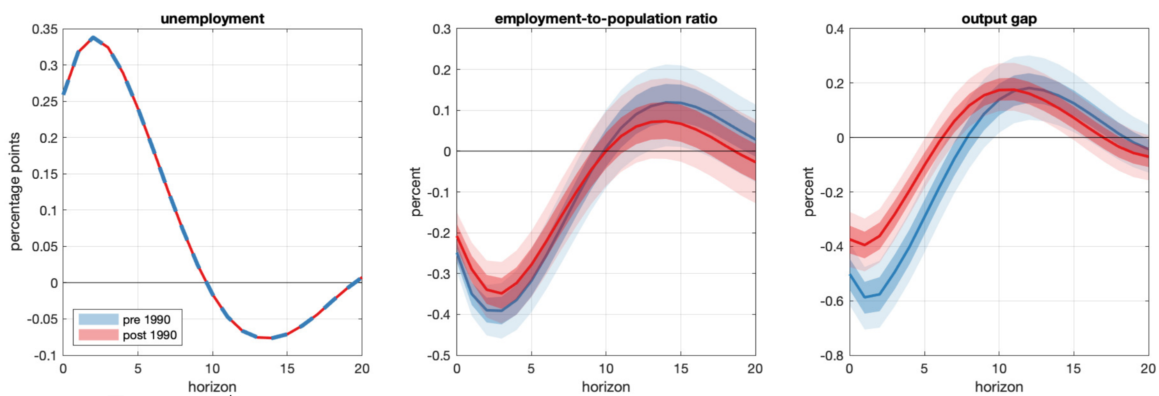

FIGURE A.5. Responses of the employment-to-population ratio and the output gap, conditional on unemployment following the path in the first subplot. These responses are computed by applying the methodology described in section 3.1 to the baseline VAR of section 2.2, augmented with the logarithm of the employment-to-population ratio and of the ratio between GDP and potential GDP from the Congressional Budget Office (CBO). The solid lines are posterior medians, while the shaded areas correspond to 68- and 95-percent posterior credible regions. The pre- and post-1990 samples consist of data from 1964:II to 1989:IV, and from 1989:I to 2019:III, respectively.

impact on the main results. Inflation is much more stable in the second sample, while the dynamics of the real variables change little.

Impulse responses to a typical business cycle shock. Finally, as a complementary exercise, figure A.8 presents the impulse responses of unemployment and inflation to a typical business cycle shock. We define this shock as the linear combination of structural

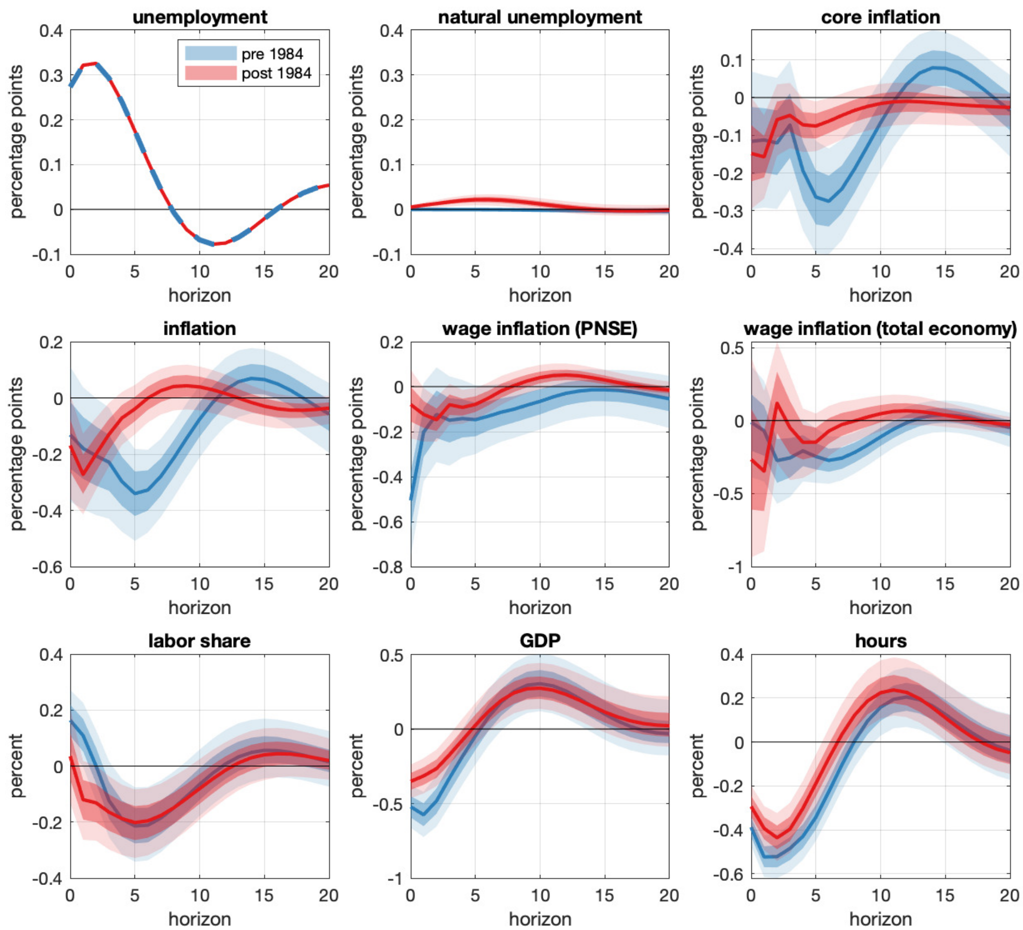

FIGURE A.6. Responses of all variables, conditional on unemployment following the path in the first subplot. These responses are computed by applying the methodology described in section 3.1 to the baseline VAR of section 2.2. The solid lines are posterior medians, while the shaded areas correspond to 68- and 95-percent posterior credible regions. The pre- and post-1984 samples consist of data from 1964:II to 1983:IV, and from 1983:I to 2019:III, respectively.

disturbances that drives the largest share of unemployment variation at business cycle frequencies, as in Giannone et al. (2019) and Angeletos et al. (2019).[36] The impulse responses

[36]More precisely, we compute the spectral density of y_t implied by the VAR representation (2.1). We use this spectrum to evaluate the variance of unemployment at business cycle frequencies (those related to periods of length between 6 and 32 quarters, as in Stock and Watson, 1999), as a function of the columns of all possible $\Sigma^{\frac{1}{2}}$ matrices. The BC shock is pinned down by the column associated with the maximal variance of unemployment at these frequencies. For technical details and the specific implementation of this idea, see Giannone et al. (2019) and Angeletos et al. (2019).

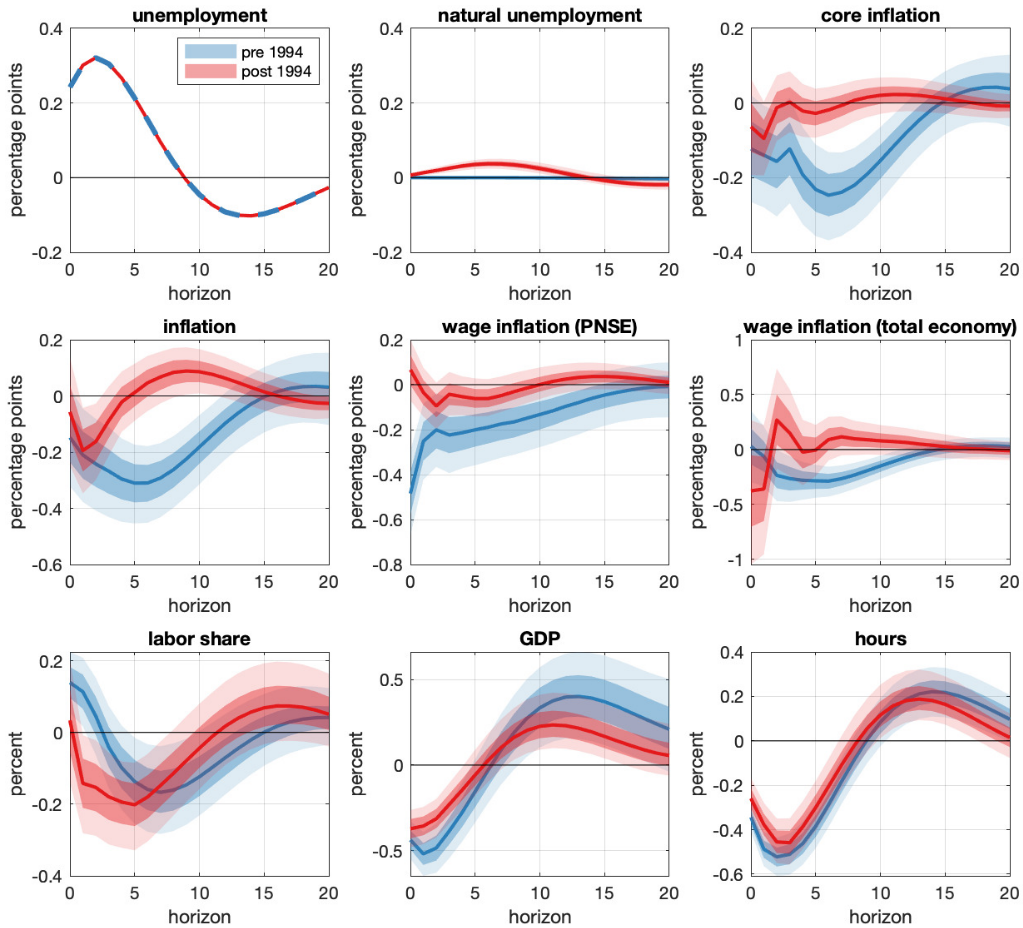

FIGURE A.7. Responses of all variables, conditional on unemployment following the path in the first subplot. These responses are computed by applying the methodology described in section 3.1 to the baseline VAR of section 2.2. The solid lines are posterior medians, while the shaded areas correspond to 68- and 95-percent posterior credible regions. The pre- and post-1994 samples consist of data from 1964:II to 1993:IV, and from 1993:I to 2019:III, respectively.

computed following this approach are essentially identical to those of figure 3.1, suggesting that the two combinations of structural shocks—the one responsible for the bulk of business cycle fluctuations and the one associated with the one-step-ahead forecast error in unemployment—are virtually the same.

Appendix B. Details on the DSGE Model

This appendix provides some details of the DSGE model used in section 6.

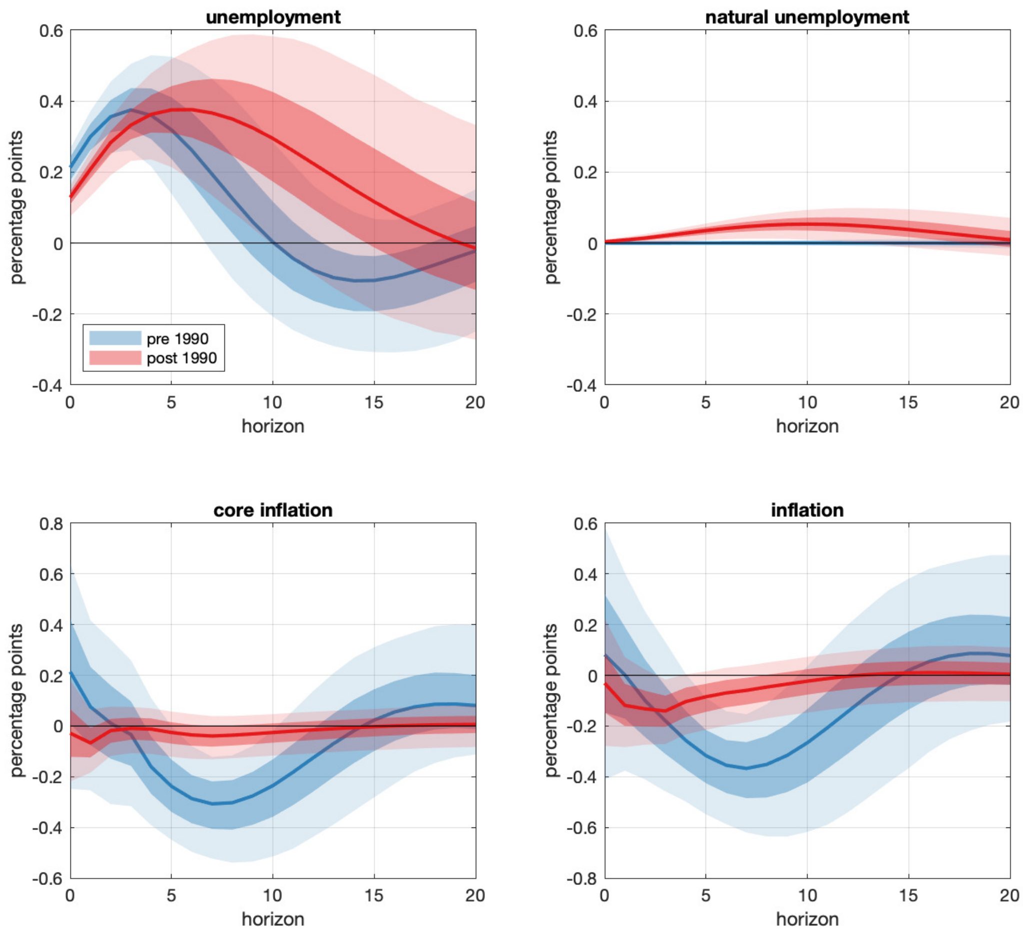

FIGURE A.8. Impulse responses of unemployment and price inflation to a business cycle shock. The impulse responses are from the baseline VAR described in section 2.2. The business cycle shock is the linear combination of structural disturbances that drives the highest share of unemployment variation at business cycle frequencies, and it is identified using the methodology of Giannone et al. (2019) and Angeletos et al. (2019). The solid lines are posterior medians, while the shaded areas correspond to 68- and 95-percent posterior credible regions. The pre- and post-1990 samples consist of data from 1964:II to 1989:IV, and from 1989:I to 2019:III, respectively.

B.1. **Equilibrium conditions.** The model economy is populated by eight classes of agents: 1) a continuum of households, who consume and supply differentiated labor; 2) competitive labor aggregators that combine labor supplied by individual households; 3) competitive final good-producing firms that aggregate the intermediate goods into a final product; 4) a continuum of monopolistically competitive intermediate good producing firms; 5) competitive capital producers that convert final goods into capital; 6) a continuum of entrepreneurs who purchase capital using both internal and borrowed funds and rent it to intermediate good producing firms; 7) a representative bank collecting deposits from the households and lending funds to the entrepreneurs; and finally 8) a government, composed of a monetary authority that sets short-term interest rates and a fiscal authority that sets public spending and collects taxes. We solve each agent's problem, and derive the resulting equilibrium conditions, which we approximate around the non-stochastic steady state. Since the derivation follows closely the literature (e.g.Christiano et al., 2005), we describe here the log-linearized conditions.

Growth in the economy is driven by technological progress, $Z_t^* = e^{\frac{1}{1-\alpha}\tilde{z}_t} Z_t^p e^{\gamma t}$, which is assumed to include a deterministic trend ($e^{\gamma t}$), a stochastic trend (Z_t^p), and a stationary component ($\tilde{z}_t$), where α is the income share of capital (after paying mark-ups and fixed costs in production). Trending variables are divided by Z_t^* to express the model's equilibrium conditions in terms of the stationary variables. In what follows, all variables are expressed in log deviations from their steady state, and steady-state values are denoted by $*$-subscripts.

The stationary component of productivity $\tilde{z}_t$ and the growth rate of the stochastic trend $z_t^p = log(Z_t^p/Z_{t-1}^p)$ are assumed to follow AR(1) processes:

$$\tilde{z}_t = \rho_z \tilde{z}_{t-1} + \sigma_z \varepsilon_{z,t},\ \varepsilon_{z,t} \sim N(0,1). \tag{B.1}$$

$$z_t^p = \rho_{z^p} z_{t-1}^p + \sigma_{z^p} \epsilon_{z^p,t},\ \epsilon_{z^p,t} \sim N(0,1). \tag{B.2}$$

The growth rate of technology evolves thus according to

$$z_t \equiv log(Z_t^*/Z_{t-1}^*) - \gamma = \frac{1}{1-\alpha}(\tilde{z}_t - \tilde{z}_{t-1}) + z_t^p, \tag{B.3}$$

where γ is the steady-state growth rate of the economy.

The *optimal allocation of consumption* satisfies the following Euler equation:

$$\begin{aligned} c_t = &-\frac{1-\bar{h}}{\sigma_c(1+\bar{h})}\left(R_t - E_t[\pi_{t+1}] + cy_t\right) + \frac{\bar{h}}{1+\bar{h}}\left(c_{t-1} - z_t\right) \\ &+ \frac{1}{1+\bar{h}} E_t\left[c_{t+1} + z_{t+1}\right] + \frac{(\sigma_c - 1)}{\sigma_c(1+\bar{h})}\frac{w_* L_*}{c_*}\left(L_t - E_t[L_{t+1}]\right), \end{aligned} \tag{B.4}$$

where c_t is consumption, L_t denotes hours worked, R_t is the nominal interest rate, and π_t is inflation. The parameter σ_c captures the degree of relative risk aversion while $\bar{h} \equiv he^{-\gamma}$

depends on the degree of habit persistence in consumption, h, and steady-state growth. This equation includes hours worked because utility is non-separable in consumption and leisure.

The convenience yield cy_t contains both a liquidity component cy_t^l and a safety component cy_t^s

$$cy_t = cy_t^l + cy_t^s, \tag{B.5}$$

where we let each premium be given by the sum of two AR(1) processes, one that captures highly persistent movements ($cy_t^{P,l}$ and $cy_t^{P,s}$) with autoregressive coefficients fixed at .99, and one that captures transitory fluctuations ($\tilde{cy}_t^{P,l}$ and $\tilde{cy}_t^{P,s}$).

The *optimal investment decision* satisfies the following relationship between the level of investment i_t, measured in terms of consumption goods, and the value of capital in terms of consumption q_t^k:

$$i_t = \frac{q_t^k}{S'' e^{2\gamma}(1+\bar{\beta})} + \frac{1}{1+\bar{\beta}}\left(i_{t-1} - z_t\right) + \frac{\bar{\beta}}{1+\bar{\beta}} E_t\left[i_{t+1} + z_{t+1}\right] + \mu_t. \tag{B.6}$$

This relationship shows that investment is affected by investment adjustment costs (S'' is the second derivative of the adjustment cost function) and by an exogenous process μ_t, which we call "marginal efficiency of investment", that alters the rate of transformation between consumption and installed capital (see Greenwood et al. (1998)). The shock μ_t follows an AR(1) process with parameters ρ_μ and σ_μ. The parameter $\bar{\beta} \equiv \beta e^{(1-\sigma_c)\gamma}$ depends on the intertemporal discount rate in the household utility function, β, on the degree of relative risk aversion σ_c, and on the steady-state growth rate γ.

The *capital stock*, $\bar{k}_t$, which we refer to as "installed capital", evolves as

$$\bar{k}_t = \left(1 - \frac{i_*}{\bar{k}_*}\right)\left(\bar{k}_{t-1} - z_t\right) + \frac{i_*}{\bar{k}_*} i_t + \frac{i_*}{\bar{k}_*} S'' e^{2\gamma}(1+\bar{\beta})\mu_t, \tag{B.7}$$

where $i_*/\bar{k}_*$ is the steady state investment to capital ratio. Capital is subject to variable capacity utilization u_t; *effective capital* rented out to firms, k_t, is related to $\bar{k}_t$ by:

$$k_t = u_t - z_t + \bar{k}_{t-1}. \tag{B.8}$$

The optimality condition determining the *rate of capital utilization* is given by

$$\frac{1-\psi}{\psi} r_t^k = u_t, \tag{B.9}$$

where r_t^k is the rental rate of capital and ψ captures the utilization costs in terms of foregone consumption.

Real marginal costs for firms are given by

$$mc_t \;=\; w_t + \alpha L_t - \alpha k_t, \tag{B.10}$$

where w_t is the real wage. From the optimality conditions of goods producers it follows that all firms have the same *capital-labor ratio*:

$$k_t \;=\; w_t - r_t^k + L_t. \tag{B.11}$$

We include financial frictions in the model, building on the work of **?**, Christiano et al. (2003), De Graeve (2008), and **?**. We assume that banks collect deposits from households and lend to entrepreneurs who use these funds as well as their own wealth to acquire physical capital, which is rented to intermediate goods producers. Entrepreneurs are subject to idiosyncratic disturbances that affect their ability to manage capital. Their revenue may thus turn out to be too low to pay back the loans received by the banks. The banks therefore protect themselves against default risk by pooling all loans and charging a spread over the deposit rate. This spread may vary as a function of entrepreneurs' leverage and riskiness.

The *realized return on capital* is given by

$$\tilde{R}_t^k - \pi_t = \frac{r_*^k}{r_*^k + (1-\delta)} r_t^k + \frac{(1-\delta)}{r_*^k + (1-\delta)} q_t^k - q_{t-1}^k, \tag{B.12}$$

where $\tilde{R}_t^k$ is the gross nominal return on capital for entrepreneurs, r_*^k is the steady state value of the rental rate of capital r_t^k, and δ is the depreciation rate.

The *excess return on capital* (the spread between the expected return on capital and the riskless rate) can be expressed as a function of the convenience yield cy_t, the entrepreneurs' leverage (i.e. the ratio of the value of capital to net worth), and "risk shocks" $\tilde{\sigma}_{\omega,t}$ capturing mean-preserving changes in the cross-sectional dispersion of ability across entrepreneurs (see **?**):

$$E_t\left[\tilde{R}_{t+1}^k - R_t\right] = cy_t + \zeta_{sp,b}\left(q_t^k + \bar{k}_t - n_t\right) + \tilde{\sigma}_{\omega,t}, \tag{B.13}$$

where n_t is entrepreneurs' net worth, $\zeta_{sp,b}$ is the elasticity of the credit spread to the entrepreneurs' leverage $(q_t^k + \bar{k}_t - n_t)$. $\tilde{\sigma}_{\omega,t}$ follows an AR(1) process with parameters ρ_{σ_ω}

and σ_{σ_ω}. *Entrepreneurs' net worth* n_t evolves in turn according to

(B.14)
$$\begin{aligned} n_t &= \zeta_{n,\tilde{R}^k}\left(\tilde{R}^k_t - \pi_t\right) - \zeta_{n,R}\left(R_{t-1} - \pi_t + cy_{t-1}\right) + \zeta_{n,qK}\left(q^k_{t-1} + \bar{k}_{t-1}\right) + \zeta_{n,n}n_{t-1} \\ & -\gamma_* \tfrac{v_*}{n_*} z_t - \tfrac{\zeta_{n,\sigma_\omega}}{\zeta_{sp,\sigma_\omega}} \tilde{\sigma}_{\omega,t-1}, \end{aligned}$$

where the ζ's denote elasticities, that depend among others on the entrepreneurs' steady-state default probability $F(\bar{\omega})$, where γ_* is the fraction of entrepreneurs that survive and continue operating for another period, and where v_* is the entrepreneurs' real equity divided by Z^*_t, in steady state.

The *production function* is

$$y_t = \Phi_p\left(\alpha k_t + (1-\alpha) L_t\right), \tag{B.15}$$

where $\Phi_p = 1 + \Phi/y_*$, and Φ measures the size of fixed costs in production. The *resource constraint* is:

$$y_t = g_* g_t + \frac{c_*}{y_*} c_t + \frac{i_*}{y_*} i_t + \frac{r^k_* k_*}{y_*} u_t. \tag{B.16}$$

where $g_t = log(\frac{G_t}{Z^*_t y_* g_*})$ and $g_* = 1 - \frac{c_* + i_*}{y_*}$. *Government spending* g_t is assumed to follow the exogenous process:

$$g_t = \rho_g g_{t-1} + \sigma_g \varepsilon_{g,t} + \eta_{gz}\sigma_z \varepsilon_{z,t}.$$

Optimal decisions for price and wage setting deliver the *price and wage Phillips curves*, which are respectively:

$$\pi_t = \kappa_p mc_t + \frac{\iota_p}{1+\iota_p\bar{\beta}}\pi_{t-1} + \frac{\bar{\beta}}{1+\iota_p\bar{\beta}} E_t[\pi_{t+1}] + \lambda_{f,t}, \tag{B.17}$$

and

(B.18)
$$\begin{aligned} w_t = \frac{(1-\zeta_w\bar{\beta})(1-\zeta_w)}{(1+\bar{\beta})\zeta_w((\lambda_w - 1)\epsilon_w + 1)}\left(w^h_t - w_t\right) - \frac{1+\iota_w\bar{\beta}}{1+\bar{\beta}}\pi_t + \frac{1}{1+\bar{\beta}}\left(w_{t-1} - z_t + \iota_w \pi_{t-1}\right) \\ + \frac{\bar{\beta}}{1+\bar{\beta}} E_t\left[w_{t+1} + z_{t+1} + \pi_{t+1}\right] + \lambda_{w,t}, \end{aligned}$$

where $\kappa = \frac{(1-\zeta_p\bar{\beta})(1-\zeta_p)}{(1+\iota_p\bar{\beta})\zeta_p((\Phi_p - 1)\epsilon_p + 1)}$, the parameters ζ_p, ι_p, and ϵ_p are the Calvo parameter, the degree of indexation, and the curvature parameter in the Kimball aggregator for prices, and ζ_w, ι_w, and ϵ_w are the corresponding parameters for wages. w^h_t measures the household's marginal rate of substitution between consumption and labor, and is given by:

$$w_t^h = \frac{1}{1-\bar{h}}\left(c_t - \bar{h}c_{t-1} + \bar{h}z_t\right) + \nu_l L_t, \tag{B.19}$$

where ν_l characterizes the curvature of the disutility of labor (and would equal the inverse of the Frisch elasticity in the absence of wage rigidities). The mark-ups $\lambda_{f,t}$ and $\lambda_{w,t}$ follow the exogenous ARMA(1,1) processes:

$$\lambda_{f,t} = \rho_{\lambda_f}\lambda_{f,t-1} + \sigma_{\lambda_f}\varepsilon_{\lambda_f,t} - \eta_{\lambda_f}\sigma_{\lambda_f}\varepsilon_{\lambda_f,t-1},$$

and

$$\lambda_{w,t} = \rho_{\lambda_w}\lambda_{w,t-1} + \sigma_{\lambda_w}\varepsilon_{\lambda_w,t} - \eta_{\lambda_w}\sigma_{\lambda_w}\varepsilon_{\lambda_w,t-1}.$$

Finally, the monetary authority follows a *policy feedback rule*:

$$\begin{aligned} R_t &= \rho_R R_{t-1} + (1-\rho_R)\left(\psi_1(\pi_t - \pi_t^*) + \psi_2(y_t - y_t^*)\right) \\ &\quad + \psi_3\left((y_t - y_t^*) - (y_{t-1} - y_{t-1}^*)\right) + r_t^m. \end{aligned} \tag{B.20}$$

where π_t^* is a time-varying inflation target, y_t^* is a measure of the "full-employment level of output," and r_t^m captures exogenous departures from the policy rule.

The time-varying inflation target π_t^* is meant to capture the rise and fall of inflation and interest rates in the estimation sample.[37] As in Aruoba and Schorfheide (2010) and Del Negro and Eusepi (2011), we use data on long-run inflation expectations in the estimation of the model. This allows us to pin down the target inflation rate to the extent that long-run inflation expectations contain information about the central bank's objective. The time-varying *inflation target* evolves according to

$$\pi_t^* = \rho_{\pi^*}\pi_{t-1}^* + \sigma_{\pi^*}\epsilon_{\pi^*,t}, \tag{B.21}$$

where $0 < \rho_{\pi^*} < 1$ and $\epsilon_{\pi^*,t}$ is an iid shock. We model π_t^* as a stationary process, although our prior for ρ_{π^*} will force this process to be highly persistent.

The "full-employment level of output" y_t^* represents the level of output that would obtain if prices and wages were fully flexible and if there were no markup shocks. This variable along with the natural rate of interest r_t^* are obtained by solving the model without nominal

[37]The assumption that the inflation target moves exogenously is of course a simplification. A more realistic model would for instance relate movements in trend inflation to the evolution of the policy makers' understanding of the output-inflation trade-of, as in **?** or **?**.

rigidities and markup shocks (that is, equations (B.4) through (B.19) with $\zeta_p = \zeta_w = 0$, and $\lambda_{f,t} = \lambda_{w,t} = 0$).

The exogenous component of the policy rule r_t^m evolves according to the following process

$$r_t^m = \rho_{r^m} r_{t-1}^m + \epsilon_t^R + \sum_{k=1}^{K} \epsilon_{k,t-k}^R, \tag{B.22}$$

where ϵ_t^R is the usual contemporaneous policy shock, and $\epsilon_{k,t-k}^R$ is a policy shock that is known to agents at time $t-k$, but affects the policy rule k periods later, that is, at time t. We assume that $\epsilon_{k,t-k}^R \sim N(0, \sigma_{k,r}^2)$, *i.i.d.* As argued in Laseen and Svensson (2011), such anticipated policy shocks allow us to capture the effects of the zero lower bound on nominal interest rates, as well as the effects of forward guidance in monetary policy.

B.2. **State Space Representation and Data.** We use the method in Sims (2002) to solve the system of log-linear approximate equilibrium conditions and obtain the transition equation, which summarizes the evolution of the vector of state variables s_t:

$$s_t = \mathcal{T}(\theta) s_{t-1} + \mathcal{R}(\theta)\epsilon_t. \tag{B.23}$$

where θ is a vector collecting all the DSGE model parameters and ϵ_t is a vector of all structural shocks. The state-space representation of our model is composed of the transition equation (B.23), and a system of measurement equations:

$$Y_t = \mathcal{D}(\theta) + \mathcal{Z}(\theta) s_t, \tag{B.24}$$

mapping the states into the observable variables Y_t, which we describe in detail next.

The estimation of the model is based on data on real output growth (including both GDP and GDI measures), consumption growth, investment growth, real wage growth, hours worked, inflation (measured by core PCE and GDP deflators), short- and long- term interest rates, 10-year inflation expectations, market expectations for the federal funds rate up to 6 quarters ahead, Aaa and Baa credit spreads, and total factor productivity growth unadjusted for variable utilization. Measurement equations (B.24) relate these observables to the model variables as follows:

(B.25)

$$
\begin{array}{lcl}
\text{GDP growth} & = & 100\gamma + (y_t - y_{t-1} + z_t) + e_t^{gdp} - e_{t-1}^{gdp} \\
\text{GDI growth} & = & 100\gamma + (y_t - y_{t-1} + z_t) + e_t^{gdi} - e_{t-1}^{gdi} \\
\text{Consumption growth} & = & 100\gamma + (c_t - c_{t-1} + z_t) \\
\text{Investment growth} & = & 100\gamma + (i_t - i_{t-1} + z_t) \\
\text{Real Wage growth} & = & 100\gamma + (w_t - w_{t-1} + z_t) \\
\text{Hours} & = & \bar{L} + L_t \\
\text{Core PCE Inflation} & = & \pi_* + \pi_t + e_t^{pce} \\
\text{GDP Deflator Inflation} & = & \pi_* + \delta_{gdpdef} + \gamma_{gdpdef} * \pi_t + e_t^{gdpdef} \\
\text{FFR} & = & R_* + R_t \\
\text{FFR}^e_{t,t+j} & = & R_* + E_t\left[R_{t+j}\right],\ j = 1, ..., 6 \\
\text{10y Nominal Bond Yield} & = & R_* + E_t\left[\frac{1}{40}\sum_{j=0}^{39} R_{t+j}\right] + e_t^{10y} \\
\text{10y Infl. Expectations} & = & \pi_* + E_t\left[\frac{1}{40}\sum_{j=0}^{39} \pi_{t+j}\right] \\
\text{Baa - 10-year Treasury Spread} & = & cy_*^l + cy_*^s + SP_* + E_t\frac{1}{80}\sum_{j=0}^{79}\left[\tilde{R}^k_{t+j+1} - R_{t+j}\right] + e_t^{Baa} \\
\text{TFP growth, demeaned} & = & z_t + \frac{\alpha}{1-\alpha}(u_t - u_{t-1}) + e_t^{tfp}.
\end{array}
$$

All variables are measured in percent. The terms π_* and R_* measure respectively the net steady-state inflation rate and short-term nominal interest rate, expressed in percentage terms, and $\bar{L}$ captures the mean of hours (this variable is measured as an index). We assume that some of the variables are measured with "error," that is, the observed value equals the model implied value plus an AR(1) exogenous process e_t^* that can be thought of either measurement errors or some other unmodeled source of discrepancy between the model and the data, as in Boivin and Giannoni (2006). For instance, the terms e_t^{gdp} and e_t^{gdi} capture measurement error of total output.[38] Alternatively, for the long-term nominal interest rate, the term e_t^{10y} captures fluctuations in term premia not captured by the model.

B.3. **Inference, Prior and Posterior Parameter Estimates.** We estimate the model using Bayesian techniques. This requires the specification of a prior distribution for the

[38] We introduce correlation in the measurement errors for GDP and GDI, which evolve as follows:

$$
\begin{array}{lcl}
e_t^{gdp} & = & \rho_{gdp} \cdot e_{t-1}^{gdp} + \sigma_{gdp}\epsilon_t^{gdp},\ \epsilon_t^{gdp} \sim i.i.d.N(0,1) \\
e_t^{gdi} & = & \rho_{gdi} \cdot e_{t-1}^{gdi} + \varrho_{gdp} \cdot \sigma_{gdp}\epsilon_t^{gdp} + \sigma_{gdi}\epsilon_t^{gdi},\ \epsilon_t^{gdi} \sim i.i.d.N(0,1).
\end{array}
$$

The measurement errors for GDP and GDI are thus stationary in *levels*, and enter the observation equation in first differences (e.g. $e_t^{gdp} - e_{t-1}^{gdp}$ and $e_t^{gdp} - e_{t-1}^{gdp}$). GDP and GDI are also cointegrated as they are driven by a comment stochastic trend.

model parameters. For most parameters common with Smets and Wouters (2007), we use the same marginal prior distributions. As an exception, we favor a looser prior than Smets and Wouters (2007) for the quarterly steady state inflation rate π_*; it is centered at 0.75% and has a standard deviation of 0.4%. Regarding the financial frictions, we specify priors for the parameters SP_*, $\zeta_{sp,b}$, ρ_{σ_ω}, and σ_{σ_ω}, while we fix the parameters corresponding to the steady state default probability and the survival rate of entrepreneurs, respectively. In turn, these parameters imply values for the parameters of (B.14). Information on the priors is provided in Table 2.

B.4. **Data Construction.** Data on real GDP (GDPC), the GDP deflator (GDPDEF), core PCE inflation (PCEPILFE), nominal personal consumption expenditures (PCEC), and nominal fixed private investment (FPI) are produced at a quarterly frequency by the Bureau of Economic Analysis, and are included in the National Income and Product Accounts (NIPA). Average weekly hours of production and nonsupervisory employees for total private industries (AWHNONAG), civilian employment (CE16OV), and the civilian noninstitutional population (CNP16OV) are produced by the Bureau of Labor Statistics (BLS) at a monthly frequency. The first of these series is obtained from the Establishment Survey, and the remaining from the Household Survey. Both surveys are released in the BLS Employment Situation Summary. Since our models are estimated on quarterly data, we take averages of the monthly data. Compensation per hour for the non-farm business sector (COMPNFB) is obtained from the Labor Productivity and Costs release, and produced by the BLS at a quarterly frequency. The data are transformed following Smets and Wouters (2007), with the exception of the civilian population data, which are filtered using the Hodrick-Prescott filter to remove jumps around census dates. The federal funds rate is obtained from the Federal Reserve Board's H.15 release at a business day frequency. We take quarterly averages of the annualized daily data and divide by four. Let Δ denote the temporal difference operator. Then:

$$
\begin{array}{lll}
\text{Output growth} & = & 100 * \Delta LN((GDPC)/CNP16OV) \\
\text{Consumption growth} & = & 100 * \Delta LN((PCEC/GDPDEF)/CNP16OV) \\
\text{Investment growth} & = & 100 * \Delta LN((FPI/GDPDEF)/CNP16OV) \\
\text{Real wage growth} & = & 100 * \Delta LN(COMPNFB/GDPDEF) \\
\text{Hours worked} & = & 100 * LN((AWHNONAG * CE16OV/100)/CNP16OV) \\
\text{GDP Deflator Inflation} & = & 100 * \Delta LN(GDPDEF) \\
\text{Core PCE Inflation} & = & 100 * \Delta LN(PCEPILFE) \\
\text{FFR} & = & (1/4) * FEDERAL\ FUNDS\ RATE
\end{array}
$$

Long-run inflation expectations are obtained from the Blue Chip Economic Indicators survey and the Survey of Professional Forecasters available from the FRB Philadelphia's Real-Time Data Research Center. Long-run inflation expectations (average CPI inflation over the next 10 years) are available from 1991Q4 onward. Prior to 1991Q4, we use the 10-year expectations data from the Blue Chip survey to construct a long time series that begins in 1979Q4. Since the Blue Chip survey reports long-run inflation expectations only twice a year, we treat these expectations in the remaining quarters as missing observations and adjust the measurement equation of the Kalman filter accordingly. Long-run inflation expectations $\pi_t^{O,40}$ are therefore measured as

$$\text{10y Infl Exp} = (\text{10-year average CPI inflation forecast} - 0.50)/4.$$

where 0.50 is the average difference between CPI and GDP annualized inflation from the beginning of the sample to 1992. We divide by 4 to express the data in quarterly terms.

We measure *Spread* as the annualized Moody's Seasoned Baa Corporate Bond Yield spread over the 10-Year Treasury Note Yield at Constant Maturity. Both series are available from the Federal Reserve Board's H.15 release. Like the federal funds rate, the spread data are also averaged over each quarter and measured at a quarterly frequency. This leads to:

$$\text{Spread} = (1/4) * (Baa\ Corporate\ -\ 10\ year\ Treasury).$$

Similarly,

$$\text{10y Bond yield} = (1/4) * (10\ year\ Treasury).$$

Lastly, TFP growth is measured using John Fernald's TFP growth series, unadjusted for changes in utilization. That series is demeaned, divided by 4 to express it in quarterly growth rates, and divided by Fernald's estimate of $(1-\alpha)$ to convert it in labor augmenting terms:

$$\text{TFP growth, demeaned } = (1/4){*}(\text{Fernald's TFP growth, unadjusted, demeaned})\ /(1-\alpha).$$

Appendix C. Additional Tables and Figures

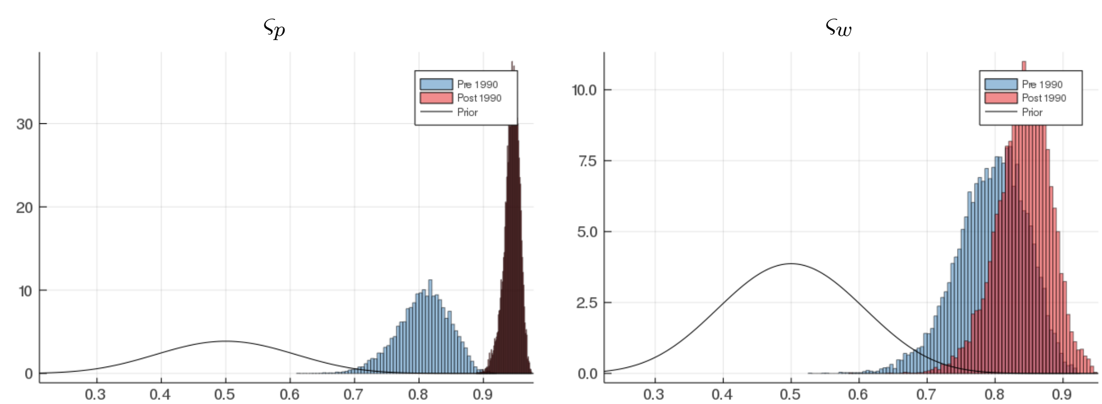

Figure C.1. Prior and posterior distributions for some additional parameters of the NY Fed DSGE model described in section 6 and appendix B.4. The pre- and post-1990 samples consist of data from 1964:II to 1989:IV, and from 1990:I to 2019:III, respectively.

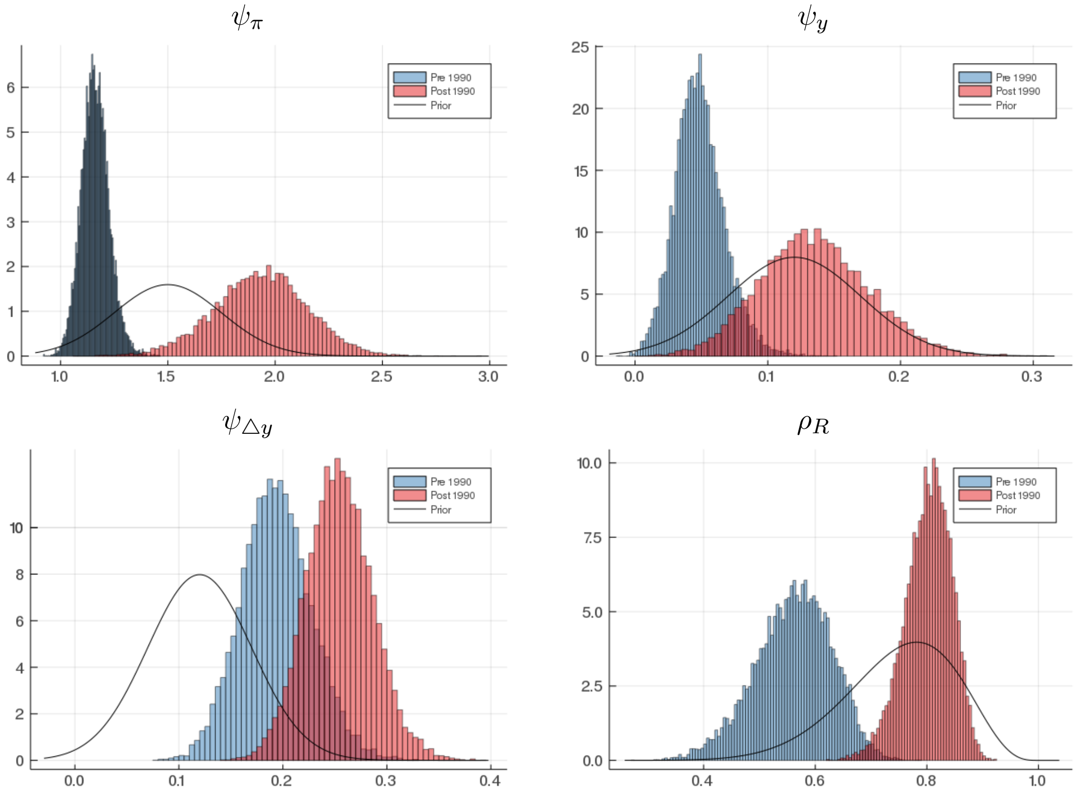

FIGURE C.2. Prior and posterior distributions for selected parameters of the NY Fed DSGE model described in section 6 and appendix B.4. In this experiment, the model is estimated allowing for two distinct monetary policy regimes, pre- and post-1990, but assuming that all other coefficients are constant for the entire sample that now excludes the ZLB period, from 1964:II to 2008:III.

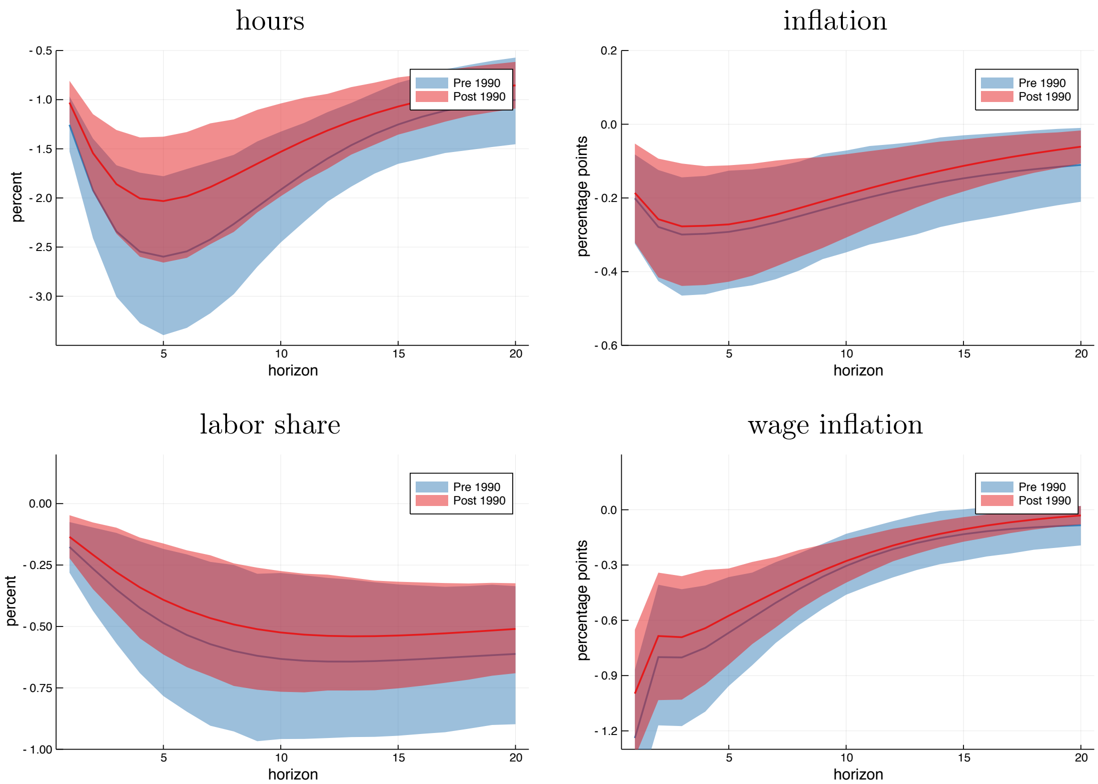

FIGURE C.3. Impulse responses of hours worked, price inflation, the labor share, and wage inflation to a shock to the unemployment equation. The impulse responses are from the VAR approximation of the NY Fed DSGE model described in section 6 and appendix B.4. The shock is identified using a Cholesky strategy, with unemployment ordered first. The solid lines are posterior medians, while the shaded areas correspond to 95-percent posterior credible regions. In this experiment, the model is estimated allowing for two distinct monetary policy regimes, pre- and post-1990, but assuming that all other coefficients are constant for the entire sample that now excludes the ZLB period, from 1964:II to 2008:III.

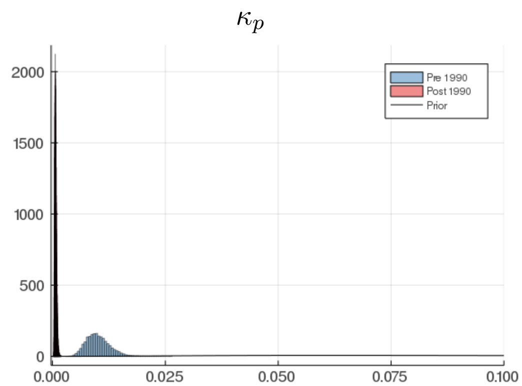

FIGURE C.4. Prior and posterior distributions for the slope of the price Phillips curve in the NY Fed DSGE model described in section 6 and appendix B.4. In this experiment, the model is estimated allowing for two distinct regimes for the slope of the price Phillips curve, pre- and post-1990, but assuming that all other coefficients are constant for the entire sample from 1964:II to 2019:III.

	Dist	Mean	Std Dev		Dist	Mean	Std Dev
Policy Parameters							
ψ_1	Normal	1.50	0.25	ρ_{r^m}	Beta	0.50	0.20
ψ_2	Normal	0.12	0.05	σ_{r^m}	InvG	0.10	2.00
ψ_3	Normal	0.12	0.05	σ_{ant1}	InvG	0.20	4.00
ρ_R	Beta	0.75	0.10				
Nominal Rigidities Parameters							
ζ_p	Beta	0.50	0.10	ζ_w	Beta	0.50	0.10
ι_p	Beta	0.50	0.15	ι_w	Beta	0.50	0.15
ϵ_p	-	10.00	fixed	ϵ_w	-	10.00	fixed
Other Endogenous Propagation and Steady State Parameters							
100γ	Normal	0.40	0.10	S''	Normal	4.00	1.50
α	Normal	0.30	0.05	ψ	Beta	0.50	0.15
$100(\beta^{-1}-1)$	Gamma	0.25	0.10	π_*	-	0.50	fixed
σ_c	Normal	1.50	0.37	γ_{gdpdef}	Normal	1.00	2.00
h	Beta	0.70	0.10	δ_{gdpdef}	Normal	0.00	2.00
ν_l	Normal	2.00	0.75	$\bar{L}$	Normal	-45.00	5.00
δ	-	0.03	fixed	λ_w	-	1.50	fixed
Φ_p	Normal	1.25	0.12	g_*	-	0.18	fixed
Financial Frictions Parameters							
$F(\bar{\omega})$	-	0.03	fixed	$\zeta_{sp,b}$	Beta	0.05	0.00
SP_*	Gamma	2.00	0.10	γ_*	-	0.99	fixed
Exogenous Process Parameters							
ρ_g	Beta	0.50	0.20	σ_g	InvG	0.10	2.00
ρ_b	Beta	0.50	0.20	σ_b	InvG	0.10	2.00
ρ_μ	Beta	0.50	0.20	σ_μ	InvG	0.10	2.00
$\rho_z til$	Beta	0.50	0.20	$\sigma_{\tilde{z}}$	InvG	0.10	2.00
ρ_{σ_ω}	Beta	0.75	0.15	σ_{σ_ω}	InvG	0.05	4.00
ρ_{π_*}	-	0.99	fixed	σ_{π_*}	InvG	0.03	6.00
ρ_{z^p}	Beta	0.50	0.20	σ_{z^p}	InvG	0.10	2.00
ρ_{λ_f}	Beta	0.50	0.20	σ_{λ_f}	InvG	0.10	2.00
ρ_{λ_w}	Beta	0.50	0.20	σ_{λ_w}	InvG	0.10	2.00
η_{λ_f}	Beta	0.50	0.20	η_{gz}	Beta	0.50	0.20

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