Oil Prices, Monetary Policy and Inflation Surges

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Abstract

We develop a simple quantitative New Keynesian model aimed at accounting for the recent sudden and persistent rise in inflation, with emphasis on the role of oil shocks and accommodative monetary policy. The model features oil as a complementary good for households and as a complementary input for firms. It also allows for unemployment and real wage rigidity. We estimate the key parameters by matching model impulse responses to those from identified money and oil shocks in a structural VAR. We then show that our model does a good job of explaining unemployment and inflation since 2010, including the recent inflation surge that began in mid 2021. We show that mainly accounting for this surge was a combination of oil price shocks and "easy" monetary policy, even after allowing for demand shocks and shocks to labor market tightness. Essential for the quantitative impact of the oil price shock is a low elasticity of substitution between oil and labor, which we estimate to be the case.

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1 Introduction

From the mid 1990s to the summer of 2021, inflation remained relatively low and stable. This behavior reinforced conventional wisdom that so long as long-term inflation expectations remained anchored, high inflation would remain a phenomenon of the past.[1] Seen in this context, the initial spurt in inflation in 2021 was thought by many (including the Federal Reserve!) to be transitory, the product of short-lived factors including a relative shift in spending from services to goods in conjunction with supply-chain problems. However, high inflation has persisted through mid 2023 despite expectations remaining reasonably anchored and supply-chain disruptions moderating.[2] These events suggest a clear need to revisit the sources of inflation.

In this paper, we develop and estimate a simple New Keynesian model designed to account for the sources of the recent inflation surge. We place particular emphasis on two factors: first, the dramatic increase in oil prices which began in the summer of 2021 and accelerated in early 2022 in response to the Ukraine war; second, easy monetary policy in the form of a delayed response of the Federal Reserve to the rise in inflation that began in 2021. Our framework also allows for other factors thought to be relevant, including increasing demand and shocks to labor market tightness. We show that even though we do not target inflation in our estimation, the model does a good job of explaining inflation since 2010, including the recent surge.

Section 2 presents the model, a variant of a standard New Keynesian framework with consumption goods only. In particular, we follow Blanchard and Gali (2007) by including oil as both a consumption good and an input into production. An important difference is that we allow for oil to be complementary with other consumption goods for households and a complementary input with labor for firms. As we make clear in section 4, a low elasticity of substitution between oil and labor is essential to match quantitatively the impact of oil shocks on inflation.[3] We also allow for unemployment via search and matching in the labor market, which enables us to consider shocks to market tightness as a source of inflation. Finally, we add several features to the model

[1] For evidence on the relative importance of long-horizon inflation expectations for postwar inflation dynamics, see Hazell et al. (2022).

[2] Alcedo et al. (2022) shows that by April 2022, shortages for most categories of goods had moderated significantly since the peak two years earlier, with food being a notable exception.

[3] Bachmann et al. (2022) emphasize how oil being a strong complementary input enhances the impact of an oil shock on output. That is true in our case as well. We also emphasize the impact on inflation.

which improve the empirical performance, including habit formation and real wage rigidity. For tractability, we do not consider supply-chain disruptions. Nevertheless, as we show below, our model tracks the inflation surge reasonably well without this factor.

Section 3 presents the mechanism through which the model can produce inflation surges. We characterize how a low elasticity of substitution between oil and labor enhances the sensitivity of marginal cost and hence inflation to oil price shocks. We also describe how labor tightness affects marginal cost and inflation. We finally show, similar to Blanchard and Gali (2007), how real wage rigidity introduces a short-run unemployment/inflation trade-off. This trade-off is important for understanding why the central bank may want to accommodate at least some of the inflation.

In section 4 we estimate the key parameters of the model. We do so by matching the model-implied impulse responses to a set of impulse responses from an estimated structural vector autoregression (SVAR). We consider two types of observable exogenous shocks. The first is a high-frequency oil shock, identified as in Känzig (2021). The second is a high-frequency shock to monetary policy, identified as in Gertler and Karadi (2015) and Bauer and Swanson (2023). Each shock serves as an external instrument in the SVAR. We choose to match impulse responses from both oil and money shocks to ensure the model responds realistically to observable supply and demand disturbances.

In section 5 we present the results. We first show that the model impulse responses match well those from the SVAR for both the oil and money shocks. We then illustrate how complementarities enhance the impact of oil price shocks and also how the short-run unemployment inflation trade-off matters.

In section 6 we explore how well the model accounts for recent inflation. We use the estimated model to perform a historical decomposition over the period 2010:01-2023:04. We identify a set of core shocks by targeting a key set of real variables, leaving untargeted the nominal variables including headline and core inflation. We then show that mainly accounting for the inflation surge was a combination of oil price shocks and easy money shocks, even after controlling for shocks to demand and labor market tightness. These results are also robust to factoring in the monetary tightening from forward guidance that began in late 2021. Concluding remarks are in section 7.

Related Literature. Before proceeding we briefly describe how our paper fits into the literature. As suggested earlier, our framework is most closely related to Blanchard and Gali (2007)'s New Keynesian model with oil and real wage rigidity. It differs by making oil a complementary good for households and a complementary input for firms and by including unemployment through search and matching. In addition, we estimate the model as described earlier. Also relevant is the literature that estimates New Keynesian DSGE models with oil, including Soto and Medina (2005), Bodenstein and Guerrieri (2011), Bodenstein et al. (2012), and Blanchard and Riggi (2013), among others. We differ by estimating the model by matching the impulse responses of identified money and oil shocks. In addition, our focus is on explaining the recent inflation surge. Our model also incorporates features thought to be relevant to recent events, such as labor market tightness, but, at the same time, it is streamlined relative to the earlier DSGE literature.

Our paper is also connected to the rapidly growing literature on the recent inflation surge.[4] As in Lorenzoni and Werning (2023), we emphasize the role of production complementarities and wage rigidity in inflation surges. As in Bernanke and Blanchard (2023), we place emphasis on the role of oil shocks in the surge. We differ by taking a more explicit model-based approach and also by considering the role of accommodative monetary policy. A number of papers have emphasized the reallocation towards goods and supply chain problems to explain the rise in inflation in 2021, including Guerrieri et al. (2021), Comin and Johnson (2021), Ferrante et al. (2023), Di Giovanni et al. (2022). Our focus is more on the inflation that persisted through mid 2023 and the role of oil prices and monetary policy. Closer to our emphasis is Ball et al. (2022), Amiti et al. (2022), Benigno and Eggertsson (2023), and Pflueger (2023), though we differ significantly in approach and details.

2 The Model

The starting point is a standard New Keynesian model with consumption goods only. We add oil which is a complement good for households and a complement input for firms. There are two types of firms. Competitive wholesale firms produce intermediate goods using labor and oil. These firms add workers via a search and matching process.

[4]See Reis (2022) for an overview of possible explanations for the recent inflation.

The wholesale firms then sell their output to monopolistically competitive retailers that package the intermediate input into final goods. Retailers also set nominal prices on a staggered basis, which introduces nominal price rigidity as in the standard NK model. We also introduce several features that improve the empirical performance of the model, including habit formation and real wage rigidity.

We next describe the elements of the model.

2.1 Households

There is a representative household with a continuum of members of measure unity. The number n_t of members are currently employed. The household provides perfect consumption insurance for its members. Family members currently not employed look for a job. A search and matching process that we describe shortly determines employment n.

Each period the household consumes a composite c_t that is the following CES aggregate of final consumption goods c_{qt} and oil c_{ot}:

$$c_t = \left(\chi^{\frac{1}{\psi}} c_{ot}^{1-\frac{1}{\psi}} + (1-\chi)^{\frac{1}{\psi}} c_{qt}^{1-\frac{1}{\psi}} \right)^{\frac{1}{1-\frac{1}{\psi}}}, \tag{1}$$

where $\psi > 0$ is the elasticity of substitution between the two goods and χ determines the share of oil in consumption. As we show later, our estimates suggest that $\psi < 1$, implying that the goods are complements. Finally, c_{qt} is a composite of a continuum of differentiated retail consumption goods, but we defer a description of the demand for these differentiated goods until later.

Let β be the subjective discount factor and ε_{bt} a discount factor shock, which serves effectively as a demand shock. The household's objective depends on the utility gain from consumption, as follows:

$$E_t \sum_{i=0}^{\infty} \beta^i \varepsilon_{bt} \ln(c_{t+i} - hc_{t-1+i}), \tag{2}$$

where $h \in (0,1)$ is the degree of habit persistence. As is standard, we allow for habit formation to capture the hump-shaped dynamics in real activity that is present in the data (as we elaborate shortly).

The household receives wage income from its employed members and unemployment insurance from the unemployed ones. Let w_{ct} denote the real wage and b_t unemployment insurance, both in units of the consumption composite. In addition, the household has the option of saving in the form of a nominal bond B_t that pays the gross nominal rate R_t^n. Let p_{ct} be the nominal price of c_t. The overall budget constraint is then given by:

$$c_t = w_{ct}n_t + b_t(1-n_t) + R_{t-1}^n \frac{p_{ct-1}}{p_{ct}} B_{t-1} - B_t + \Pi_t, \tag{3}$$

where Π_t is total net payments to the household, which includes dividends from ownership of firms and net lump sum taxes paid to the government. Conditional on n_t, the household chooses c_t, B_t, c_{qt} and c_{ot} to maximize (2) given (3) and (1).

Let u_{ct} be the marginal utility of consumption:

$$u_{ct} = \frac{1}{c_t - hc_{t-1}} - \frac{\beta h}{c_{t+1} - hc_t}.$$

Then, from the household's consumption/saving decision:

$$1 = E_t \left\{ \Lambda_{t,t+1} R_t^n \frac{p_{ct}}{p_{ct+1}} \right\},$$

where $R_t^n \frac{p_{ct}}{p_{ct+1}}$ is the real return on the nominal bond and $\Lambda_{t,t+1} = \beta \frac{u_{ct+1}}{u_{ct}}$ is the household's stochastic discount factor.

Next, let p_{qt} and p_{ot} be the nominal prices of c_{qt} and c_{ot}, respectively, and $s_t = p_{ot}/p_{ct}$ the relative price of oil. From cost minimization, we obtain demand functions for consumption goods and oil:

$$c_{qt} = (1-\chi) \left(\frac{p_{qt}}{p_{ct}} \right)^{-\psi} c_t, \tag{4}$$

$$c_{ot} = \chi s_t^{-\psi} c_t. \tag{5}$$

Combining (4) and (5) with (1) yields a price index for p_{ct}:

$$p_{ct} = \left(\chi p_{ot}^{1-\psi} + (1-\chi) p_{qt}^{1-\psi} \right)^{\frac{1}{1-\psi}}.$$

2.2 Unemployment, Vacancies, and Matching

As we noted earlier, production and employment take place in the wholesale sector. We describe wholesale firms shortly. In the meantime, we characterize the search and matching process. The approach follows closely Mortensen and Pissarides (1994). At time t, each wholesale firm i employs $n_t(i)$ workers and posts $v_t(i)$ vacancies to attract new workers. To post each vacancy a firm must pay the fixed cost c. Total employment and vacancies are given by $n_t = \int_0^1 n_t(i)di$ and $v_t = \int_0^1 v_t(i)di$. All unemployed workers at t look for jobs. We assume that those unemployed who find a job go to work immediately within the period. Accordingly, the stock u_t of unemployed workers entering period t is the difference between the labor force (which we fix at unity) and the stock n_{t-1} of employed workers at the end of $t-1$:

$$u_t = 1 - n_{t-1}.$$

The number of new hires Φ_t is governed by the following matching function with constant returns to scale that is increasing in both vacancies and unemployment:

$$\Phi_t = \varepsilon_{\Phi t} u_t^{\sigma} v_t^{1-\sigma}, \tag{6}$$

where the random variable $\varepsilon_{\Phi t}$ is a shock to match efficiency. The shock could also reflect shifts in the search effort by the unemployed or recruiting intensity by firms. Note that a decline in $\varepsilon_{\Phi t}$ acts like a negative shock to labor supply, as it implies that more vacancies are needed to create the same amount of matches. This leads to an outward shift in the Beveridge curve (the relation between vacancies and unemployment) and therefore an increase in labor market tightness.

Next, the probability q_t a firm fills a vacancy in period t is given by:

$$q_t = \frac{\Phi_t}{v_t}. \tag{7}$$

In turn, the probability a worker finds a job f_t is:

$$f_t = \frac{\Phi_t}{u_t}.$$

Firms and workers take both q_t and f_t as given.

Finally, in each period an exogenous fraction of workers $1-\rho$ separate from the firm at which they were employed and become unemployed.

2.3 Wholesale Firms

Competitive wholesale firms produce and sell output to retail firms. Wholesale firm i makes output y_t using input of labor n_t and oil o_t according to the following CES production (where we drop the firm subscript i for convenience):

$$y_t = \left(\alpha^{\frac{1}{\epsilon}} n_t^{1-\frac{1}{\epsilon}} + (1-\alpha)^{\frac{1}{\epsilon}} o_t^{1-\frac{1}{\epsilon}}\right)^{\frac{1}{1-\frac{1}{\epsilon}}}, \tag{8}$$

where ϵ is the elasticity of substitution between labor and oil. As we show, our estimates suggest a value of ϵ well below unity, implying that oil and labor are strong complementary inputs.

Employment at t is the sum of surviving workers from the previous period, ρn_{t-1} and new hires, where the latter is the product of the vacancy filling probability and total vacancies, $q_t v_t$. That is, we can write:

$$n_t = \rho n_{t-1} + q_t v_t. \tag{9}$$

The firm can thus adjust current employment by posting vacancies, taking q_t as given.[5]

We next turn to the firm's objective. Let p_{wt} be the wholesale firm's relative price, $w_{qt} = w_{ct}(p_{ct}/p_{qt})$ the real product wage, and $s_{qt} = s_t(p_{ct}/p_{qt})$ the relative price of oil, all in units of final good output. The firm's objective then is to maximize the discounted stream of profits, F_t, given by:

$$F_t = p_{wt} y_t - w_{qt} n_t - c v_t - s_{qt} o_t + E_t \left\{ \Lambda_{t,t+1}^q F_{t+1} \right\}, \tag{10}$$

where $\Lambda_{t,t+1}^q = \beta \left(\frac{u_{ct+1}}{u_{ct}}\right) \left(\frac{p_{qt+1}/p_{ct+1}}{p_{qt}/p_{ct}}\right)$ is the household's stochastic discount factor in terms of final good output. Note that profits each period are the difference between revenues $p_{wt} y_t$ and the sum of the wage bill $w_{qt} n_t$, vacancy posting costs $c v_t$, and oil costs $s_{qt} o_t$. The optimization problem is then the following: firms choose vacancies

[5] We assume the law of large numbers applies so that $q_t v_t$ is with certainty the number of new hires.

v_t, employment n_t, and oil o_t to maximize (10) subject to (8) and (9).

Let a_{nt} be the marginal product of labor. The first-order conditions for v_t and n_t along with the envelope condition yield the following standard first-order condition for hiring:

$$\begin{aligned}\frac{c}{q_t} =& \sum_{i=0}^{\infty} \rho^i E_t \left\{ \Lambda^q_{t,t+i} (p_{wt+i} a_{nt+i} - w_{qt+i}) \right\} \\ =& p_{wt} a_{nt} - w_{qt} + \rho E_t \left\{ \Lambda^q_{t,t+i} \frac{c}{q_{t+1}} \right\},\end{aligned} \tag{11}$$

where the marginal product of labor is:

$$a_{nt} = \left(\alpha \frac{y_t}{n_t} \right)^{\frac{1}{\epsilon}}. \tag{12}$$

The left-hand side of equation (11) is the marginal cost of adding a worker, given by the vacancy-posting cost divided by the probability of filling the vacancy, while the right-hand side is the marginal benefit of an extra worker, given by the expected discounted stream of per-period profits $p_{wt+i} a_{nt+i} - w_{qt+i}$.

Let a_{ot} be the marginal product of oil. The firm's demand for oil is given by the condition that the marginal value of oil equals the marginal cost:

$$p_{wt} a_{ot} = s_{qt}, \tag{13}$$

where the marginal product of oil is:

$$a_{ot} = \left((1-\alpha) \frac{y_t}{o_t} \right)^{\frac{1}{\epsilon}}.$$

So far we have described the firm's hiring decision conditional on the path of wages. We will describe shortly how wages are determined. In the meantime, it is useful to characterize the value J_t of a worker to the firm, after hiring costs have been paid. From differentiating equation (10) with respect to n_t and applying the envelope theorem, we obtain:[6]

$$J_t = \sum_{i=0}^{\infty} \rho^i E_t \left\{ \Lambda^q_{t,t+i} (p_{wt} a_{t+i} - w_{qt+i}) \right\} \\ = p_{wt} a_t - w_{qt} + \rho E_t \left\{ \Lambda^q_{t,t+1} J_{t+1} \right\}. \tag{14}$$

2.4 Workers

We next develop an expression for the worker's surplus from a job, which is critical for wage determination. Recall that $w_{ct} = w_{qt}(p_{qt}/p_{ct})$ is the real wage in units of the consumption composite. Let V_t be the value to a worker of employment at t and U_t the value of being unemployed. Then V_t and U_t are given by:

$$V_t = w_{ct} + E_t \left\{ \Lambda_{t,t+1} \left(\rho V_{t+1} + (1-\rho) U_{t+1} \right) \right\},$$

$$U_t = b_t + E_t \left\{ \Lambda_{t,t+1} \left(f_{t+1} V_{t+1} + (1 - f_{t+1}) U_{t+1} \right) \right\},$$

where w_{ct} and $b_t = b(p_{qt}/p_{ct})$ are the flow values of work and unemployment respectively, ρ is the job survival probability, and f_{t+1} is the probability of moving from unemployment in t to employment in $t+1$.

The job surplus H_t is then given by:

$$H_t = V_t - U_t \\ = w_{ct} - b_t + E_t \left\{ \Lambda_{t,t+1} \left((\rho - f_{t+1}) H_{t+1} \right) \right\}. \tag{15}$$

2.5 Wage Determination

We introduce now a simple form of real wage rigidity. We assume that the wage depends on the gap between the value that would arise under Nash bargaining and its steady-state value. The degree of stickiness is parsimoniously characterized by a single parameter that we estimate. We elaborate below.

[6]Because production is constant returns and there is a continuum of workers, the value of the marginal worker is the same as the value of the average worker.

2.5.1 Nash Bargaining Wage

Let us start by characterizing the product wage under Nash bargaining. In this hypothetical case the firm and its workers choose w_{qt} to maximize the joint surplus from the match, as follows:[7]

$$\max_{w_{qt}} H_t^{\varsigma} J_t^{1-\varsigma},$$

where $\varsigma \in [0,1]$ is the relative bargaining power of workers and H_t and J_t are as in equations (14) and (15). Maximizing with respect to w_{qt} yields the following conventional first order condition that relates the relative surpluses to the bargaining weights:

$$\frac{J_t}{H_t} = \frac{1-\varsigma}{\varsigma}. \tag{16}$$

Combining (14), (15), and (16) leads to the product wage that would arise under Nash Bargaining:

$$w_{qt}^{o} = \frac{\varsigma\left(p_{wt}a_{nt} + \rho E_t\left\{\frac{c}{q_{t+1}}\left(\Lambda_{t,t+1}^{q} - \Lambda_{t,t+1}\right)\right\} + E_t\left\{\Lambda_{t,t+1}c\theta_{t+1}\right\}\right) + (1-\varsigma)\frac{p_{qt}}{p_{ct}}b}{\varsigma + (1-\varsigma)\frac{p_{qt}}{p_{ct}}}. \tag{17}$$

As is standard, the Nash wage is a convex combination of the period surplus the worker brings to the match and the worker's outside option, where the weights depend on relative bargaining power. The term $\rho E_t\left\{\frac{c}{q_{t+1}}\left(\Lambda_{t,t+1}^{q} - \Lambda_{t,t+1}\right)\right\}$ reflects differences between the parties in the evaluation of the value of a worker due to differences in the stochastic discount factors. The presence of the relative price of goods, p_{qt}/p_{ct}, reflects how workers value the nominal wage and unemployment insurance payments differently from firms.

In what follows, we assume that the bargaining weight ς and $1-\varsigma$ equal the corresponding weights σ and $1-\sigma$ in the matching function, implying the Hosios condition holds: the equilibrium with wages determined by Nash bargaining is thus constrained efficient, in the sense that the social value of the marginal hire equals the marginal recruiting cost.

[7] Notice that the outcome is the same as with bargaining over the consumption wage w_{ct}.

2.5.2 Real Wage Rigidity

As Shimer (2005) observes, period-by-period Nash bargaining over wages leads to unemployment volatility that is too low relative to the data and wage volatility that is too high. Further, as discussed in Blanchard and Gali (2007), absent any frictions in wage determination it is difficult to explain the large effects of oil price shocks, as wages could freely adjust to dampen the impact on the economy.

Though the details differ, we follow Blanchard and Gali (2007) in introducing real wage rigidity. We suppose that the percent adjustment of the real wage relative to steady state is the fraction $1-\gamma$ of the percent fluctuation in the Nash wage w_{qt}^o, where $\gamma \in [0,1]$. In particular,

$$w_{qt} = (w_{qt}^o)^{1-\gamma}(w_q^o)^{\gamma}, \tag{18}$$

where w_q^o is the steady state Nash wage. Under reasonable parametrizations, equation (18) is consistent with rational behavior as the implied wage lies within the bargaining set, i.e. it is never above firm's reservation wage (the value to the firm of a worker) nor is it ever below worker's reservation wage (the flow value of unemployment). One way to interpret equation (18) is as the firm providing some insurance to workers by offering a smoother real wage than would be the case under period-by-period Nash bargaining. Though, we do not motivate this argument from first principles.[8] Finally, note that the parameter γ reflects the degree of real wage rigidity.

2.6 Retail Firms

There is a continuum of monopolistically competitive retail firms indexed by $j \in [0,1]$. Retailers buy intermediate goods from the wholesale firms described earlier. Retailers then transform intermediate goods into a differentiated final good. Households buy and consume these differentiated products. Finally, retail firms set prices on a staggered basis. They obey a standard time-dependent rule following Calvo: we suppose $1-\lambda$ is the probability the firm is able to change price in the current period, where the draw is i.i.d. across time and firms.

The consumption good composite for each household, c_{qt}, is given by the CES

[8] See Gertler and Trigari (2009) and Christiano et al. (2016) for formal models of real wage rigidity in a search and matching setting.

aggregate of each retail firm's output y_{jt}, as follows:

$$c_{qt} = \left(\int_0^1 y_{jt}^{\frac{\eta}{\eta-1}} dj \right)^{\frac{\eta-1}{\eta}},$$

where η is the elasticity of substitution across intermediate goods. From cost minimization, we obtain the household's demand for each retail good as an inverse function of the relative price, p_{jt}/p_{qt}, along with an expression for the price of final consumption goods, p_{qt}:

$$y_{jt} = \left(\frac{p_{jt}}{p_{qt}} \right)^{-\eta} c_{qt}, \tag{19}$$

$$p_{qt} = \left(\int_0^1 p_{jt}^{1-\eta} dj \right)^{\frac{1}{1-\eta}}.$$

In each period, the fraction λ of retail firms that are unable to adjust price simply meet demand for their differentiated final good. They do so by buying enough input from wholesalers as long as the relative output price, $\frac{p_{jt}}{p_{qt}}$, is not less than the cost of inputs, p_{wt}.

On the other hand, retail firms that are able to adjust price within the period choose the reset price p_{jt}^* and output y_{jt} to maximize expected discounted profits, subject to the demand curve (19):

$$\max_{p_{jt}^*, y_{jt}} E_t \left\{ \sum_{i=0} \lambda^i \Lambda_{t,t+i}^q \left(\frac{p_{jt}^*}{p_{qt}} - p_{wt} \right) y_{jt+i} \right\},$$

where the probability λ^i that the firm's price remains fixed i periods into the future. Note that the relative wholesale price p_{wt} corresponds to the marginal cost of production.

The first-order condition for the retailer's reset price is:

$$E_t \left\{ \sum_{i=0} \lambda^i \Lambda_{t,t+i}^q \left(\frac{p_{jt}^*}{p_{qt+i}} - (1+\mu) p_{wt+i} \right) y_{jt+i} \right\} = 0, \tag{20}$$

where $\mu = 1/(1 - 1/\eta)$ is desired net markup. When able to adjust, a firm chooses to reset the price p_{jt}^* so that, over the period in which its price is expected to remain fixed, its relative price equals a discounted weighted average of the desired gross gross markup $(1+\mu)$ over its real marginal cost p_{wt+i}.

Finally, using the law of large numbers, price index becomes:

$$p_{qt} = \left((1-\lambda)(p_t^*)^{1-\eta} + \lambda p_{t-1}^{1-\eta}\right)^{\frac{1}{1-\eta}}. \tag{21}$$

Equations (20) and (21) govern the path of goods inflation conditional on that of the real marginal cost p_{wt}.

2.7 The Oil Market and Resource Constraints

We suppose that there is a representative oil producer who acts competitively. Each period the producer receives an endowment of oil equal to $S\exp(-\varepsilon_{ot})$, where ε_{ot} is a shock to the oil supply and S is the steady-state oil supply. The producer takes the price of oil as given. All profits are paid out as dividends to households. Each period the sum of the firm demand for oil o_t and the household demand c_{ot} must equal the total supply, as follows:

$$o_t + c_{ot} = S\exp(-\varepsilon_{ot}),$$

where the respective firm and household oil demand functions are given by equations (5) and (13). The relative price of oil s_t adjusts to clear the market.[9]

For produced goods, the relevant resource constraint is given by the condition that consumption goods c_{qt} must equal output y_{qt} net hiring costs cv_t:

$$c_{qt} = y_{qt} - cv_t.$$

Finally, the supply of nominal bonds is zero:

$$B_t = 0.$$

[9] In practice, oil prices depend on both oil production and the existing stock of inventories. In particular, inventories can be used strategically to manipulate the price of oil in the short run. Despite abstracting from modeling explicitly inventories, we account for speculative behavior resulting in temporary fluctuations of oil prices in the empirical analysis, as discussed in detail in section 6.

2.8 Government Policy

We suppose that the central bank adjusts its instrument, the nominal interest rate, according to a simple Taylor rule augmented by a persistent exogenous money shock ε_{rt}:

$$R_t^n = R^n \pi_{qt}^{\phi_\pi} e^{\varepsilon_{rt}},$$

where ϕ_π is the feedback coefficient on inflation. We presume the central bank responds to core inflation (inflation absent oil prices) so as to avoid temporary gyrations associated with headline inflation.

The only fiscal expenditures are unemployment insurance payments. We suppose payments are financed by lump-sum taxes on households

$$b_t u_t = \tau_t.$$

This completes the description of the model.

3 Sources of Inflation Surges

We now characterize the features of our model that can help account for inflation surges. As discussed in section 2.6, inflation depends on the real marginal cost of final goods firms. In our model, the marginal cost corresponds to the relative price of wholesale goods p_{wt}. Let $\pi_{qt} = \ln(p_{qt}/p_{qt-1})$ be goods market inflation and $\widehat{p}_{wt} = \ln(p_{wt}/p_w)$ be the log deviation of the relative wholesale price from its steady state. Loglinearizing (20) around the zero-inflation steady state and using equation (21), then yields the following Phillips curve relation for π_{qt}:

$$\pi_{qt} = \kappa \widehat{p}_{wt} + E_t\{\pi_{qt+1}\},$$

where $\kappa = (1-\lambda)(1-\lambda\beta)/\lambda$ is the slope of the Phillips curve. As in the standard NK formulation, inflation depends on real marginal cost, which in this case is $\widehat{p}_{wt}$. Iterating forward implies that inflation depends on an expected discounted stream of present and future marginal costs, as follows:

$$\pi_{qt} = \kappa \sum_{i=0}^{\infty} E_t\left\{\widehat{p}_{wt+i}\right\}.$$

In the model, a large inflation surge originates from a significant and persistent increase in the expected path of real marginal cost.

We next decompose the movement in p_{wt} into three terms: the real wage, the marginal hiring cost, and the marginal product of labor. As we show, all three factors could play a significant role in an inflation surge. However, given the strong complementarities between labor and oil, the marginal product of labor plays a particularly important role.

From the hiring condition (11) we can derive a relation for the marginal hiring cost. Let ω_t be the net marginal cost of hiring a worker.[10] From equation (11), we can express ω_t as:

$$\omega_t = \frac{c}{q_t} - \rho E_t \left\{ \Lambda^q_{t,t+1} \frac{c}{q_{t+1}} \right\}, \tag{22}$$

which is the gross cost of adding a worker at t, c/q_t, net the expected discounted benefit that the additional worker at t will generate in the future $\rho E_t \left\{ \Lambda^q_{t,t+1} c/q_{t+1} \right\}$.[11] We can then express the marginal cost of producing a unit of output as the sum of the wage w_{qt} and net hiring costs ω_t, normalized by the marginal product of labor a_{nt}, as follows:

$$p_{wt} = \frac{w_{qt} + \omega_t}{a_{nt}}. \tag{23}$$

From loglinearizing equation (23), we can decompose marginal cost $\widehat{p}_{wt}$ into a convex combination of the real product wage $\widehat{w}_{qt}$ and net hiring costs $\widehat{\omega}_t$ minus the marginal product of labor $\widehat{a}_{nt}$, all expressed in log deviations from steady state:

$$\widehat{p}_{wt} = \zeta \widehat{w}_{qt} + (1 - \zeta)\widehat{\omega}_t - \widehat{a}_{nt}, \tag{24}$$

where $\zeta = \frac{w_q}{w_q + \omega}$ is the relative weight on the real product wage.

Equation (24) highlights how inflation surges are generated in our model. First, the presence of complementarities enhances the sensitivity of the marginal product of labor (and hence marginal cost) to fluctuations in oil intensity, measured by the ratio of oil to labor input, o_t/n_t. After combining equations (8) and (12), we can obtain

[10] Ferrante et al. (2023) also develop a role for hiring costs in affecting marginal cost in their model of sectoral reallocation with quadratic labor adjustment costs.

[11] From the hiring condition, we can infer that c/q_{t+1} equals the present value of earnings at $t+1$ and beyond generated by a worker who is with the firm at t. From the vantage of time t we take expectations and discount this value by the job survival probability ρ and the household stochastic discount factor $\Lambda^q_{t,t+1}$.

the following loglinear approximation for the marginal product of labor:

$$\widehat{a}_{nt} = \frac{1}{\epsilon}(1-\overline{\alpha})(\widehat{o}_t - \widehat{n}_t),$$

with:

$$\overline{\alpha} = \frac{\alpha}{\alpha + \alpha^{1-\frac{1}{\epsilon}}(1-\alpha)^{\frac{1}{\epsilon}}(\frac{o}{n})^{1-\frac{1}{\epsilon}}} \approx \alpha.$$

Note first that under our calibration $\overline{\alpha} \approx \alpha$ since $o/n \approx (1-\alpha)/\alpha$. The equation then makes clear how, as the elasticity of substitution ϵ declines, the sensitivity of $\widehat{a}_{nt}$ to $\widehat{o}_t - \widehat{n}_t$ increases. With sufficiently strong complementarities, even a small oil shock that reduces oil intensity can produce a sharp decline in $\widehat{a}_{nt}$ contributing to a surge in inflation via its impact on costs $\widehat{p}_{wt}$. Similarly, given that the oil supply is fixed in the short run, a positive demand shock that reduces $\widehat{o}_t - \widehat{n}_t$ by increasing labor demand also generates inflationary pressures that are stronger when the elasticity of substitution ϵ is small.

Second, wage rigidity also matters. With flexible wages, in response to an increase in oil prices, wages may drop significantly, moderating the impact of the oil shock on marginal cost. Therefore, wage rigidity dampens this offsetting adjustment and thus amplifies the transmission of supply shocks to inflation.

Third, labor market tightness $\theta_t = v_t/u_t$ affects the marginal cost. Note first that from equations (6) and (7) the vacancy filling probability q_t varies inversely with tightness, i.e. $q_t = \varepsilon_{\Phi t}\theta_t^{-\sigma}$. Replacing this in equation (22), we can express net hiring costs as a linear function of current and expected market tightness:

$$\widehat{\omega}_t = \frac{1}{1-\rho\beta} E_t \left\{ \sigma\widehat{\theta}_t - \rho\beta\sigma\widehat{\theta}_{t+1} - \rho\beta\widehat{\Lambda}^q_{t,t+1} + \ln\varepsilon_{\Phi t} - \rho\beta\ln\varepsilon_{\Phi t+1} \right\}. \tag{25}$$

Equations (24) and (25) illustrate how, via net hiring costs $\widehat{\omega}_t$, market tightness $\widehat{\theta}_t$ affects marginal cost $\widehat{p}_{wt}$. In addition, from equation (17), the real wage is increasing in expected labor market tightness as the latter increases the value of unemployment. Both forces imply that a tightening of labor market conditions raises marginal cost, which thus applies upward pressure on prices.

Finally, the conduct of monetary policy is critical. How much inflation emerges from forces that put upward pressure on marginal cost ultimately depends on the degree of monetary accommodation. For example, if the central bank tightens sufficiently, inflation will not increase. The question then becomes whether there is a short-run trade-off between inflation and (the efficient level of) real activity that might induce some accommodation from the central bank. Absent such a trade-off there is no reason for a central bank to accommodate the inflationary pressures.

As in Blanchard and Gali (2007), a short-run trade-off between inflation and real activity arises due to the presence of real wage rigidity. Since we differ in a number of details, it is useful to illustrate how this trade-off arises within our framework. First, suppose that retail firms receive lump sum subsidies so that there is no distortion from imperfect competition in the flexible price equilibrium. Then, with sticky prices and flexible wages, monetary policy can achieve the first best outcome by setting demand so that the markup $1/p_{wt}$ equals its first best value, $1+\mu$. In this instance, inflation will equal its optimal value of zero, as $\widehat{p}_{wt}$ in the Phillips curve (3) will be zero. Hiring and employment will also be efficient, given the wage is set each period by Nash bargaining and our parametric assumptions ensure that the Hosios condition is satisfied. In this case, absent real wage rigidity, there is no trade-off.

Now consider real wage rigidity. Let $\widehat{p}^{o}_{wt}$ be the "Nash" marginal cost, i.e. the marginal cost if wages were determined each period by Nash bargaining. It follows from equation (18) that we can express marginal cost as:

$$\begin{aligned}\widehat{p}_{wt} =& \zeta(1-\gamma)\widehat{w}^{o}_{qt} + (1-\zeta)\widehat{\omega}_t - \widehat{a}_{nt} \\ =& \widehat{p}^{o}_{wt} - \gamma\widehat{w}^{o}_{qt}.\end{aligned} \tag{26}$$

Equation (26) makes clear that the wage only adjusts partially to the Nash wage, by the factor $1-\gamma$. Notice that with wage rigidity ($\gamma > 0$), actual marginal cost $\widehat{p}_{wt}$ differs from its value under Nash bargaining $\widehat{p}^{o}_{wt}$.

We can illustrate the trade-off by combining (26) with the loglinearized Phillips curve to obtain:

$$\pi_{qt} = \kappa\widehat{p}^{o}_{wt} + E_t\pi_{qt+1} + \Delta_t.$$

where the cost-push term depends on the deviation of the wage from the Nash wage as follows:

$$\Delta_t = -\kappa\gamma\widehat{w}^{o}_{qt}.$$

Absent real wage rigidity ($\gamma = 0$), Δ_t is equal to zero, implying no trade-off. However, with $\gamma > 0$ and supply shocks to the economy, it is not possible to simultaneously achieve price stability along with the efficient level of economic activity.

To illustrate the trade-off, consider a negative oil supply shock. The shock puts upward pressure on marginal cost by reducing the marginal product of labor a_{nt}. It also reduces the Nash wage. However, due to the rigidity, the actual wage falls by less than the Nash wage, implying an increase in the cost-push term Δ_t. If the central bank chooses to adjust demand to keep $\widehat{p}^o_{wt}$ to zero, then the cost-push term will generate an increase in inflation. If it chooses to not accommodate the inflation, it must contract demand to push $\widehat{p}^o_{wt}$ negative in order to offset the impact of the cost-push term.[12] The net effect is that stabilizing prices in response to the oil shock requires reducing economic activity below the efficient level, something that would not be necessary if wages were fully flexible. Accordingly, the supply shock confronts the central bank with a short-run trade-off, which provides a rationale for why it may accommodate some of the inflationary pressures. We illustrate this trade-off later with our estimated model.[13]

4 Model Estimation

We estimate the key parameters of the model by matching the model-implied impulse responses to a set of impulse responses generated from an estimated structural vector autoregression (SVAR).. We consider two types of observable shocks that serve as external instruments in our estimated SVAR: a supply shock and a demand shock. The supply shock is a high-frequency oil shock, identified as in Känzig (2021). The demand shock is a high-frequency shock to monetary policy, obtained as in Gertler and Karadi (2015) and Bauer and Swanson (2023).

4.1 Data

Our SVAR is monthly. The sample is 1973:01 to 2019:12. We exclude the last part of the sample to remove the pandemic period, where arguably a temporary structural

[12]From equation (26), we see that $\widehat{p}^o_{wt}$ depends positively on the Nash wage and hiring costs, which in turn depend on firm revenues and market tightness, respectively. Contractionary monetary policy reduces both and hence reduces $\widehat{p}^o_{wt}$.

[13]Depending on the details, a demand shock may not present the central bank with a similar conundrum since monetary policy transmits through the economy like a demand shock. By offsetting the demand shock, monetary policy can return the economy to the efficient level, depending on how closely monetary policy can mirror a demand shock.

change took place.[14] We include seven reasonably standard macroeconomic variables: log real gross domestic output, unemployment in levels, log real oil prices, the Federal Funds rate, log headline PCE, log real wages, and the Gilchrist and Zakrajšek (2012) excess bond premium. The latter we include in the SVAR to improve the precision of the impulse responses but do not target it.

Monthly real GDP is log cumulated real GDP growth constructed by Brave-Butters-Kelley. The real oil price is the log spot West Texas Intermediate crude oil price deflated by core PCE. The real wage is measured as log average hourly earnings by production and nonsupervisory employees deflated by core PCE. Unemployment is the number of unemployed as a percentage of the labor force (16 years or older).

4.2 Identification of the Effects of Oil and Money Shocks

Let Y_t is a $N \times 1$ vector of endogenous variables, ν_t is the corresponding vector of reduced-form residuals, B_0 is the intercept term and $B_1, \ldots, B_p$ are a set of $N \times N$ coefficient matrices. Then we start with the following reduced-form VAR(p) model which we can estimate via OLS:

$$Y_t = B_0 + B_1 Y_{t-1} + \cdots + B_p Y_{t-p} + \nu_t \tag{27}$$

The reduced form residuals may in turn be expressed as functions of primitive structural shocks ε_t, as follows:

$$\nu_t = \mathcal{I} \cdot \varepsilon_t$$

where ε_t is an $N \times 1$ vector and $\mathcal{I}$ is an $N \times N$ coefficient matrix. Let ε_{st} be the structural shock to oil and ε_{rt} the structural shock to monetary policy. We are interested in identifying the effects of these shocks on the set of reduced-form residuals. Once we have estimated these effects, we can then use the VAR to trace out the dynamic effects on the economy.

To identify exogenous variation for the oil and money shocks, we use as external instruments the surprises in futures market prices constructed around OPEC and

[14]The impulse responses for the money and oil shocks are not robust to the inclusion of the pandemic recession and recovery, likely due to the unusual dynamics of the bust and boom during this period. However, as argued by Lenza and Primiceri (2021), excluding the period is acceptable for parameter estimation purposes.

FOMC announcements, respectively. Let s_t^i be the surprise in the log price of a future contract for variable i at the announcement date t. The key assumption is that the news revealed within the window that leads to the surprise in the futures price can be treated as exogenous with respect to the other variables in the VAR. Let $\mathbb{E}_t(P_{t+h}^i)$ be the log expected spot price conditional on the information available after the announcement and $\mathbb{E}_{t-w}(P_{t+h}^i)$ be the log forecast of the same variable just prior to the window opening. Then assuming that the risk premium does not change within the window around the announcement, the surprise simplifies to:

$$s_t^i = \mathbb{E}_t(P_{t+h}^i) - \mathbb{E}_{t-w}(P_{t+h}^i)$$

Each surprise $s_t^i \in \{s_t^o, s_t^r\}$ is used as an instrumental variable to identify a column of coefficients in the structural impact matrix $\mathcal{I}$. Finally, to be a valid instrument, s_t^i must satisfy the relevance and exogeneity assumptions:

$$\mathbb{E}(s_t^i \varepsilon_t^i) \neq 0$$

$$\mathbb{E}(s_t^i \varepsilon_t^j) = 0, j \neq i$$

Under these assumptions, the column of S that corresponds to each variable i is identified up to a sign and scale with:

$$\mathcal{I}_j^i = \frac{\mathbb{E}(s_t^i \nu_t^j)}{\mathbb{E}(s_t^i \nu_t^i)}, j \neq i$$

where $\mathcal{I}_j^i$ is the two-stage least squares estimate of the regression of ν_t^j on ν_t^i with s_t^i as an instrumental variable for ν_t^i. We normalize the impact of the money shock on the Fed Funds and the impact of the oil shock on the real oil price to be one standard deviation.[15]

To construct oil price surprises we follow Känzig (2021) exactly.[16] We consider the surprise in the futures price for oil on the day in which the Organization of the Petroleum Exporting Countries (OPEC) has a meeting. The relevant time window over which the surprise takes place is between the day of the announcement and the

[15] See footnote 4 in Gertler and Karadi (2015) for the details.

[16] For some classic approaches to identifying oil shocks, see Hamilton (1983) and Kilian (2009).

last trading day before the OPEC meeting.[17]

For monetary policy surprises, we start with Gertler and Karadi (2015) by using unexpected movements in interest rate futures around Federal Open Market Committee (FOMC) dates. We then follow Bauer and Swanson (2023) by also measuring surprises around non-FOMC dates where the Federal Reserve revealed information.[18] To measure the futures market surprise we use the unexpected movement in the first principal component of the first four quarterly Eurodollar future contracts. Given data availability, we are able to use a very tight window of thirty minutes: the money shock surprise is thus the log difference between the realized value twenty minutes after the announcement and the forecast ten minutes prior to the meeting. To identify contemporaneous effects of interest rate surprises, we begin in 1988:01 given that interest rates futures data are not available until then. Note that we still use the whole sample to estimate the reduced form coefficients in the VAR.

One challenge we need to address is that oil prices have predictability for interest rate surprises: an increase in the growth of oil prices prior to the FOMC meeting predicts an increase in the surprise, which appears to violate our maintained hypothesis that the surprises are exogenous. A likely explanation involves endogeneity: monetary policy tends to ease when oil prices fall and vice versa when they rise.[19] Accordingly, we purge from our measure of the monetary surprise the information contained in oil prices, as follows: we run the regression of money surprises on the log change in oil spot prices calculated between the day before the meeting and the previous month, Δp_{ot}. We find that monetary policy surprises can

[17] Unfortunately, intraday oil futures are not available until the latter part of the sample. As discussed by Känzig (2021), markets react to OPEC announcements slower compared to FOMC announcements, and this gives further justification for using a daily window rather than a tighter one.

[18] We also do not include the measured money shock during the month of the Lehman Brothers collapse. Because the markets were expecting a larger easing, our measure shows an unanticipated tightening. At the same time, there was a huge drop in GDP and industrial production due to the financial collapse. Because factors beyond monetary policy were relevant to the drop in real activity, we thought it was prudent to drop this observation. The only effect on our VAR is that it reduces slightly the impact of a surprise tightening on real GDP.

[19] On the topic see for example Cieslak and Schrimpf (2019), Miranda-Agrippino and Ricco (2021), Bauer and Swanson (2021), and Bauer and Swanson (2023). One might argue that the effects of oil prices prior to FOMC dates on interest rates should be captured in futures markets. A reason why this might not be the case is uncertainty regarding the central bank's reaction function, leading financial markets to underestimate feedback effects from oil prices.

be predicted by oil prices:[20]

$$s_t^r = \underset{(.038)}{+.073} \cdot \Delta p_{ot} + \xi_t$$

We then use the residuals of this regression, $\hat{\xi}_t$, as the monetary policy surprises, giving us an instrument that is orthogonal to oil prices. We note that without this adjustment, our SVAR would predict that a surprise monetary tightening would increase oil prices, an outcome that is clearly the product of not properly controlling for the endogeneity of monetary policy.

4.3 Impulse Responses to Money and Oil Shocks

Figure 1 reports the impulse responses for the identified money and oil shocks along with ninety-five percent confidence bands.[21]

The IRFs for the money shock are similar to previous estimates obtained in the literature: A monetary policy tightening of 15 basis points implies a decline in GDP of about 10 basis points after ten months along with a decline in the price level of about 10 basis points. Associated with the decline in output is a rise in unemployment of roughly half a percentage point. Real wages also decline slightly, though the estimate is not statistically different from zero. After forty to fifty months all the real variables have reverted to their initial values. The real oil price declines moderately but is not statistically different from zero, in line with previous evidence in the VAR literature (e.g. Soriano and Torró 2022) as well as high-frequency evidence (e.g. Rosa 2014).

The IRFs for the oil shock behave similarly to those in Känzig (2021), though with some differences due to the variables in the VAR not being identical. The oil shock has a stagflationary effect: a shock that generates a 6 percent increase in the real price of oil reduces GDP by roughly 20 to 30 basis points and increases the price level by about 20 basis points. Interestingly, we find that the Fed funds rate increases about 20 basis points on impact and persists above zero for twenty months, suggesting that the central bank reacts to the increase in inflation with a monetary policy tightening. Real wages decline persistently by about 5 to 10 basis points,

[20]This is in line with evidence from Bauer and Swanson (2023) who use a broader information set to purge the money shock. However, when using their measure of orthogonalized money surprises, we find a positive and significant impact of money shocks on oil prices.

[21]Confidence bands are computed using the wild bootstrap.

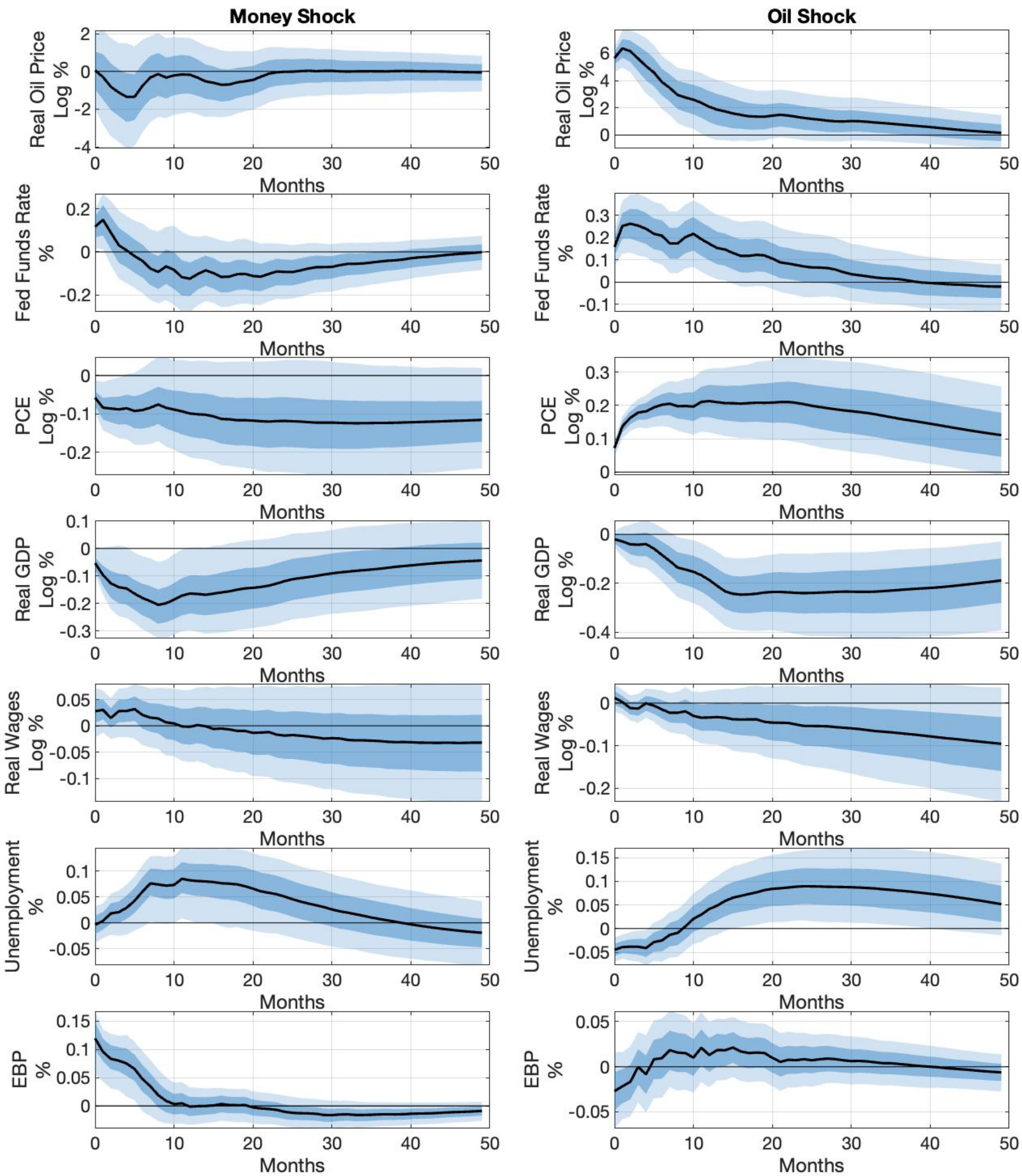

Figure 1: SVAR-based impulse responses for identified money and oil shocks. The solid line is the point estimate and the dark and light-shaded areas are 68 and 95 percent confidence bands, respectively, computed using the wild bootstrap.

mainly due to nominal wages increasing by less than core inflation.

4.4 Parameter Estimation

We first calibrate a set Θ_1 of parameters and then estimate the remaining parameters in the set Θ_2 conditional on the calibrated parameters. Parameters are estimated using the simulated method of moments to match the model impulse response functions with those from the SVAR with identified money and oil shocks, as portrayed in Figure 1. Impulse responses are weighted using the estimated precision. Confidence intervals for the parameters are derived using the delta method. We describe the details of the estimation procedure in Appendix A.

4.4.1 Calibrated Parameters

We begin with the parameters in Θ_1 which we calibrate to standard values. We start with conventional parameters. We choose the discount factor β to generate a steady-state annual real interest of two percent. We pick the elasticity of substitution between the differentiated consumption goods η to generate a steady-state gross markup of 1.3. We set the feedback coefficient on inflation in the Taylor rule to 2, a number slightly above the conventional value of 1.5 in order to compensate for the absence of the output gap in the feedback rule.[22]

We next turn to the labor market parameters. We set the job survival rate ρ to a monthly value of 0.96, implying an average employment duration of two and a half years, consistent with the evidence. As noted earlier, we also choose worker's bargaining power ς and the match elasticity σ to each equal 0.5, so that the Hosios condition is satisfied, implying that when wages are perfectly flexible and there is Nash bargaining, job creation is efficient. Next, we choose the worker's flow outside option b so that the ratio to the steady-state contribution of the worker to the match is 0.72, consistent with Hall (2009) and implying a value of b of 0.7. Finally, we set the steady-state unemployment rate equal to the sample mean of 5 percent.[23] We can then use the steady-state level of unemployment to pin down the cost of posting a vacancy c at 0.09.

[22]All the results are robust to calibrating the Taylor rule parameter to 1.5. A weaker monetary response would imply an additional half percentage point of PCE inflation due to money shocks at the peak of the 2022 inflation surge (see Section 6).

[23]Blanchard et al. (2022) estimate the natural rate to be 5%.

Next, we turn to oil. Consistent with the calibration in Bodenstein et al. (2012), we set the steady-state ratio of oil used in production to output, o/y, and the steady-state ratio of firm to household expenditures on oil o/c_o to respectively 3.0 percent and 1.5 percent. The steady-state ratio of oil to output pins down the share of labor in production α at 0.97.[24] The steady-state ratio of firm to household expenditures on oil pins down the share of oil in households' expenditures χ at 2 percent.[25]

4.4.2 Estimated Parameters

Conditional on the calibrated parameters, we then estimate nine parameters: the two parameters regulating complementarities with oil in production and consumption (ϵ and ψ), the wage rigidity parameter (γ), the habit persistence (h), the price rigidity (λ) and the persistence and volatilities of the money and oil shocks (ρ^r, ρ^o, σ^r, σ^o).

Table 1 presents the results. The estimates of ϵ and ψ, 0.37, and 0.02 respectively, suggest strong complementarities with oil in both production and consumption. Though the standard errors are large, we can reject the null of no complementarities. What is giving the high degree of complementarity in production is the sharp drop in output and increase in unemployment in response to the oil shock. With substitutability instead, the impact of the oil price shock on output would be muted as firms switch to labor and households substitute towards consumption goods. The habit formation parameter is estimated to be a monthly value of 0.91, implying a quarterly value of 0.75 which is slightly higher than estimates elsewhere.[26] The estimate of the monthly degree of price rigidity λ corresponds to an average duration of price stickiness of six quarters, which is inconsistent with the microdata which

[24] We justify the 3 percent share of oil in production as follows: first, as in Bodenstein et al. (2012), we include natural gas along with petroleum in the measure of the oil. According to the US Energy Information Administration, petroleum, and natural gas expenditures average 4.5% as a share of domestic GDP over the period 2010-2020. Finally, oil inputs in production account for about 2/3 of total oil usage, giving an estimate of the production share of 3.1% (see the next footnote).

[25] In 2021, according to the U.S. Information Energy Administration, 67.2% of petroleum consumption is accounted for by transportation, 26.9% by industrial use, 2.8% by residential, 2.5% by commercial, and 0.5% by electricity production. Transportation includes usage that can be partially attributed to the household sector and partially to the production sector. In particular, 63% of it is motor gasoline (including transportation for commercial purposes), 23% is distillate fuel oil and 10% is jet fuel and aviation gasoline. Splitting transportation usage in half between households and firms gives a division of total oil usage in 2/3 for production and 1/3 for final consumption.

[26] The high value of h may be due to the fact that the model has consumption goods only and thus abstracts from persistence due to investment adjustment costs.

Parameters Θ_1	Calibration	Parameters Θ_2	Estimate
β	.998	ϵ	.374 (.160)
η	4	ψ	.020 (.337)
ϕ_π	2	γ	.697 (.145)
ρ	.96	h	.914 (.036)
σ	.5	λ	.945 (.011)
ς	.5	ρ^r	.952 (.011)
b	.7	ρ^o	.967 (.013)
o/c_o	1.5	σ^r	.019 (.006)
o/y	.03	σ^o	.060 (.025)
u	.05		

Table 1: Values for the model parameters and steady-state targets. The first two columns report the calibrated parameters in Θ_1, the last two columns report the estimated parameters in Θ_2 with their point estimates and standard errors in brackets.

suggests much shorter spells. However, the model abstracts from real rigidities (e.g. Kimball) that would reduce the estimated stickiness of prices. The estimates also suggest considerable real wage stickiness. The estimate of the rigidity parameter γ of 0.69 implies that a change in the Nash wage from the steady state leads to a change in the actual wage of roughly one third of that amount.

5 Results

5.1 Model versus Data

Figure 2 portrays the impulse response functions from the model versus those generated by the data. The left column portrays the effect of the money shock while the right side does the same for the oil shock. In each case, the black line is the data along with ninety-five percent confidence intervals, while the red line is the model. Overall the fit is good: the model always stays within the confidence intervals. While the model response of output to each shock is below the point estimate from the data, the response of unemployment is on target, as are the responses of the other variables (to a reasonable degree).

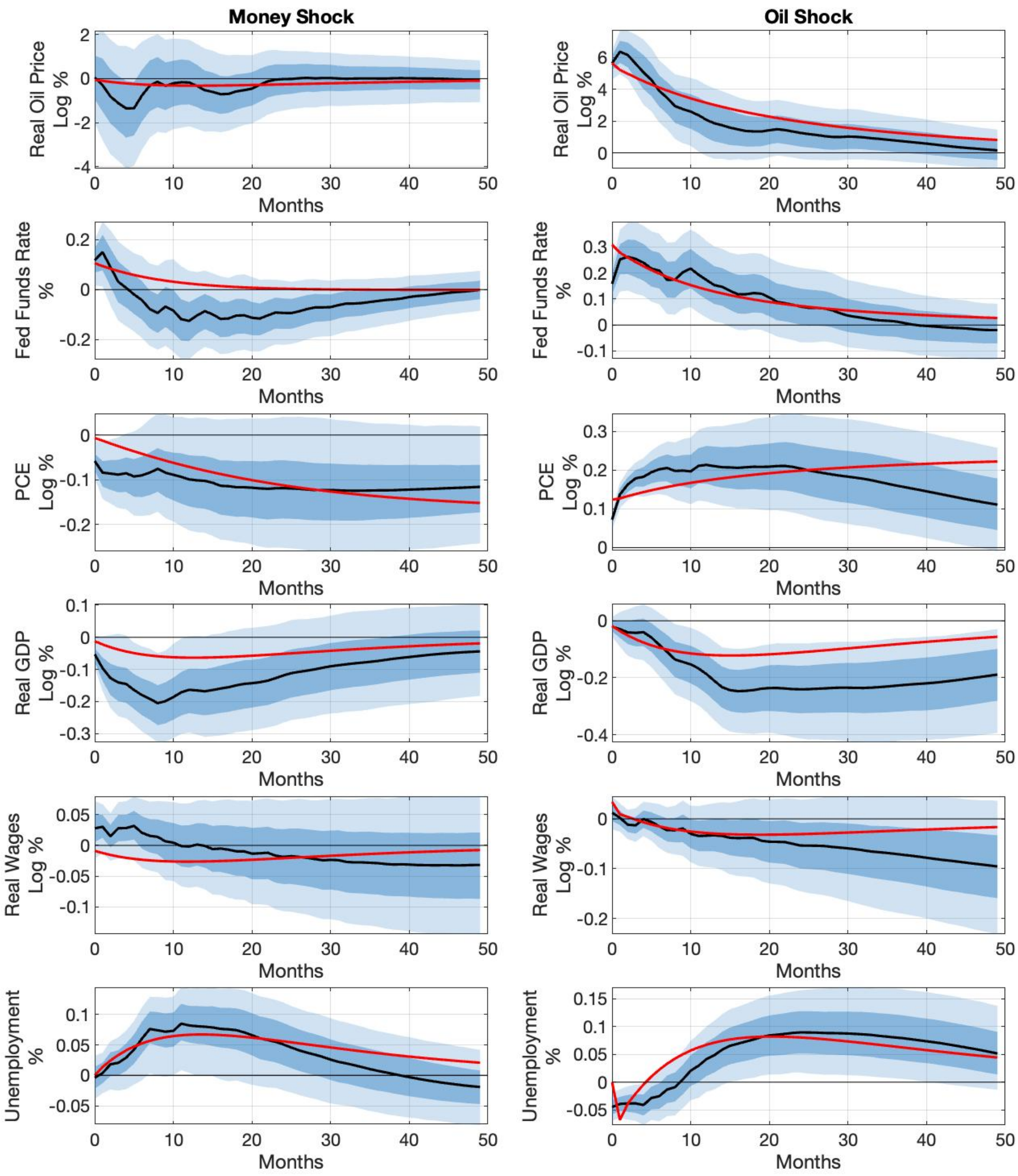

Figure 2: SVAR-based impulse responses for identified money and oil shocks vs model-based impulse responses (in red). The solid line is the point estimate and the dark and light-shaded areas are 68 and 95 percent confidence bands, respectively, computed using the wild bootstrap.

5.2 Inspecting the Mechanisms: Complementarities and Tradeoffs

Two important features of the model are: (i) complementarities in the use of oil for both firms and households and (ii) real wage rigidities, which introduce a short-run inflation/unemployment trade-off. In this subsection, we explore the quantitative implications.

For firms, in the event of an oil price shock, complementarities reduce substitution from oil to labor, enhancing the decline in labor demand. Similarly, for households, complementarities reduce spending on other goods in the wake of the oil shock. Figure 3 illustrates. It presents the responses of output, unemployment, and prices to an oil shock both for our benchmark model with complementarities and for the case where spending shares are constant for both households and firms (i.e. a Cobb-Douglas consumption composite in oil and goods and a Cobb-Douglas production function in oil and labor). The impact of the oil shock is dramatically larger with complementarities than without. For the benchmark model (the blue line) the peak drop in real GDP is 0.13 versus 0.04 in the Cobb-Douglas case (the red dotted line). Further, the large drop in the gap between the two cases is highly persistent. Similar results hold for unemployment. In the benchmark case, the oil shock induces a persistent increase in unemployment, peaking at 0.8 about two years after the shock. Absent complementarities, the effect on unemployment is minimal.

The oil shock also has a larger effect on nominal prices in the benchmark model than in the case without complementarities. The rise in core PCE is more than double in the benchmark model. Intuitively, the increase in marginal cost is much larger with complementarities, owing to the larger reduction in the marginal product of labor implying greater inflationary pressures. The PCE displays similar behavior, except there is a stronger initial jump in the price level since oil prices are included in the index. Finally, we confirm that complementarities enhance the decline in the marginal product of labor, which in turn enhances the impact on marginal cost. Of course, it is through the enhanced impact on marginal cost that complementarities magnify the effect of oil price shocks on nominal prices.

Next, we examine the short-run inflation/unemployment trade-off in the model. As noted earlier, absent such a trade-off it is had to rationalize why the central bank should accommodate inflationary pressures. Figure 4 illustrates. To provide a

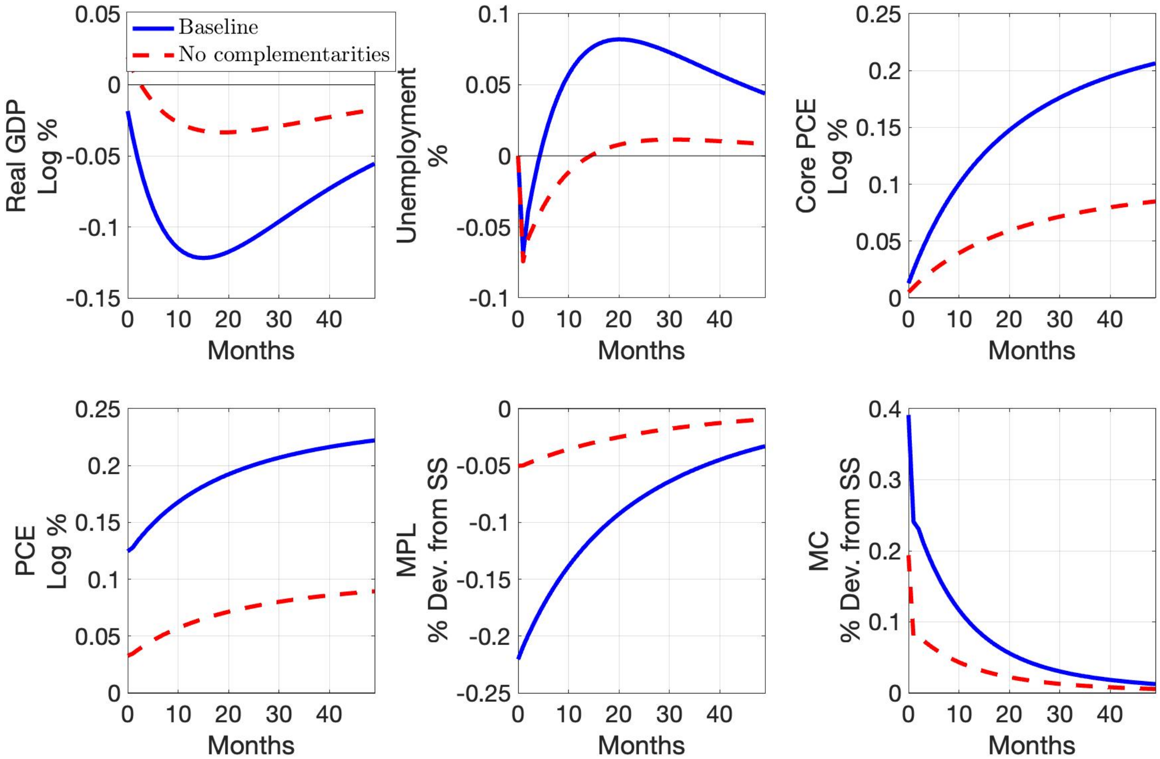

Figure 3: Impulse response functions to an oil shock. Baseline (blue) corresponds to the calibration in Table 1. The alternative (red) without complementarities ($\epsilon = 1$, $\psi = 1$).

benchmark, we start by analyzing the impact of the oil shock in the flexible price and flexible wage case. As in the standard NK framework, the flexible price equilibrium is a natural objective for policymakers. The dashed green lines in the top left and right panels reflect the responses of output and unemployment respectively to an oil shock for this case. There is a faster decline in output and rise in unemployment than in the sticky price baseline case (the blue line), but the recovery is quicker. However, the peak drops in output and unemployment are similar in the two cases. Note also that the slower drop in real activity in the baseline case generates an increase in core inflation (see the bottom left panel): roughly speaking, in the sticky price baseline case demand does not drop as much as supply initially (captured by the difference between the blue and green dashed line), which induces inflationary pressures. The PCE deflator also increases, jumping initially because it includes energy prices.

To illustrate the inflation/unemployment trade-off we next consider a policy that stabilizes the price level. With no trade-off (or equivalently with flexible wages) output and unemployment should correspond to their efficient values (i.e. their

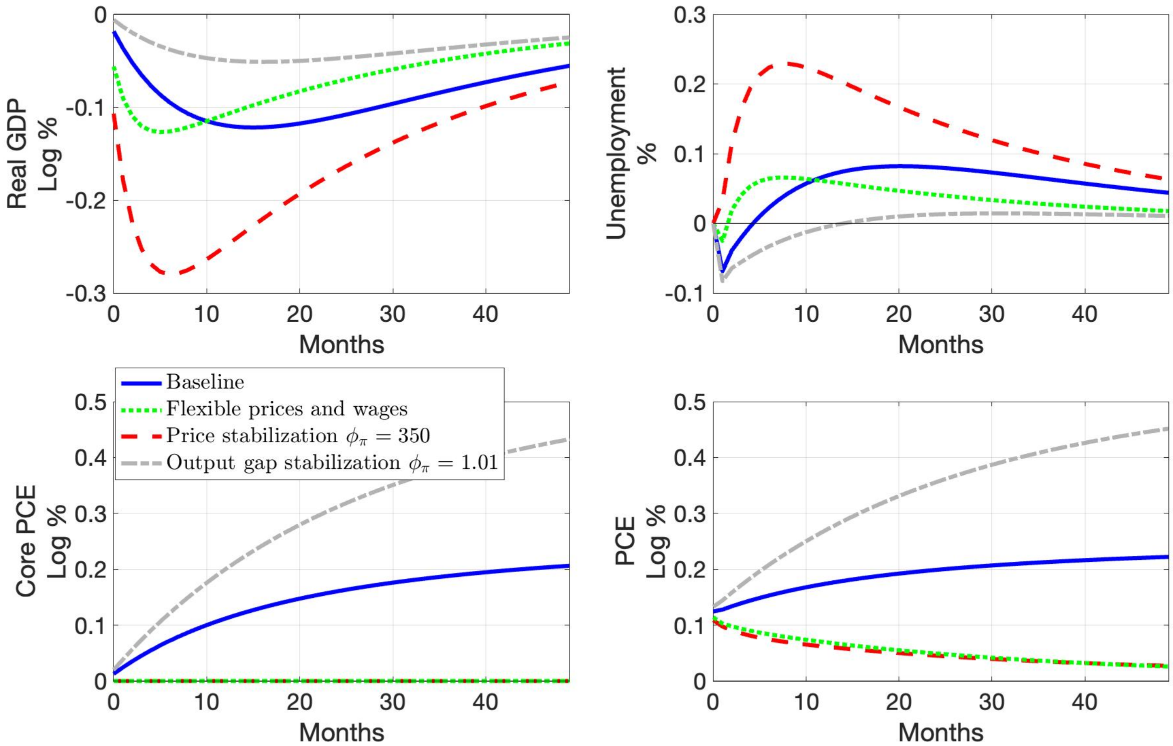

Figure 4: Impulse response functions to an oil shock. Baseline (blue) corresponds to the calibration in Table 1. Alternative 1 (green) has flexible prices and wages ($\gamma = 0$). Alternative 2 (red) is a policy counterfactual with sticky wages that stabilizes inflation ($\phi_\pi = 350$). Alternative 3 (grey) is a policy counterfactual with sticky wages that has no inflation stabilization ($\phi_\pi = 1.01$).

respective flexible price equilibrium values.) On the other hand, the dashed red line gives the case with real wage rigidity. It shows that pursuing price stability induces a much larger drop in output and increase in unemployment relative to the flexible price benchmark. Over the first eight to ten months the drop in output and the rise in unemployment are more than double their respective flexible price benchmarks. Finally, we ask what happens if the central bank pursues a highly accommodating policy by setting the Taylor rule coefficient on inflation very close to unity. The policy greatly moderates the impact of the oil shock on output and unemployment but at the cost of much higher inflation.[27]

[27] Bernanke et al. (1997) show how the monetary policy rule shapes the response to oil shocks. They show how a shift to a more accommodative policy reduces the contraction in output but leads to a stronger positive effect on the price level.

6 Accounting for Inflation

We now explore the extent to which the model can account for the recent increase in inflation, including the surge that occurred in mid 2021 and the persistence that has followed. To do so, we use the estimated model to perform a historical shock decomposition over the period 2010 to spring 2023 at a monthly frequency. We consider four shocks as driving forces: the demand shock ε_{bt}, the monetary policy shock ε_{rt}, the oil shock ε_{st} and the shock to match efficiency $\varepsilon_{\Phi t}$. As discussed earlier, these shocks span most of the popular explanations for the persistent increase in inflation. Those citing demand point to the surge in spending in 2021 due to the waning of the virus in conjunction with stimulative fiscal policy. The case for monetary policy as a source is based on the argument that over much of 2021-2022 the Fed kept rates low relative to its norm, which can be captured by the policy shock. Oil shocks come to prominence as a potential factor, beginning with the oil price increase in 2021 which gained further impetus in 2022 as a result of the war in Ukraine. Finally, some have argued that decreases in match efficiency that tightened labor markets may also have been a supply-side inflationary force.

We then proceed as follows. We take from section 4.4 all the parameter values, either calibrated or estimated.[28] Using standard Bayesian methods, we then estimate the standard deviations of all four shocks and also the persistence of the demand and matching shocks only, given that we obtained from the earlier estimation the persistence of the money and oil shocks.[29] Priors are set to standard values. Details and results are reported in Table 2 in Appendix B.

To identify the four shocks, we target four variables: the unemployment rate, real oil price inflation (in terms of PCE core), the Federal Funds rate, and labor market tightness. Oil inflation is the quarter-to-quarter annualized percent change in the real oil price; market tightness is obtained from JOLTS as the ratio between job openings and unemployed persons. From the four targeted variables, we obtain the smoothed series for the shocks using the Kalman smoother. We can then construct

[28] The advantage of estimating parameters from the impulse response matching exercise is twofold. First, we can make use of observable shocks (money and oil) and avoid taking a stand on all the (unobservable) shocks for the full sample period 1973-2023. Second, we can leave inflation untargeted in the shock decomposition and validate ex-post our results by comparing the model-implied series with actual data.

[29] Notice that matching impulse responses pins down the standard deviation of the two shocks up to a normalization, therefore we need to re-estimate these parameters.

historical decompositions.

One complication in doing this exercise is that the oil price series displays considerable high-frequency volatility, possibly due to speculation in financial markets. Some of these high-frequency gyrations in oil prices do not appear to immediately translate into prices that households and firms face, as a comparison of wholesale oil prices with the PCE price index for energy would suggest. Accordingly, we assume that oil price inflation ($\pi_{ot} = \ln(p_{ot}/p_{ot-1})$) is the sum of a persistent component ($\bar{\pi}_{ot} = \ln(\bar{p}_{ot}/\bar{p}_{ot-1})$), which translates into retail oil prices, and an i.i.d. component ε_{mt}, which reflects speculative noise:[30]

$$\pi_{ot} = \bar{\pi}_{ot} + \varepsilon_{mt}$$

The volatility of ε_{mt}, σ^m, is residually identified from the persistence of the oil shock that we previously estimated. We note however that cleaning off the high-frequency noise in oil prices only has a minor effect on the results.[31]

Since all the nominal variables are untargeted, we can judge how well the model captures inflation by constructing model-implied series for the following quarter-to-quarter annualized variables: PCE inflation, core PCE inflation, nominal wage inflation, and real product wage inflation. Variables are demeaned using the sample mean. Given the sample includes the slow recovery from the 2008 recession we take steady-state unemployment to be 5 percent, consistent with some recent estimates of the natural rate.[32]

6.1 Historical Shock Decompositions

6.1.1 Targeted Variables

Figure 5 presents a historical decomposition for the four targeted variables over the sample 2010:01-2023:04. Overall, the results are very sensible. The demand shock accounts for most of the variation in unemployment. In this vein, the model treats

[30] The price index becomes $p_{ct} = (\chi \bar{p}_{ot}^{1-\psi} + (1-\chi) p_{qt}^{1-\psi})^{\frac{1}{1-\psi}}$.

[31] In particular, there are two data points with unusually large oil price shocks that quickly revert. Without cleaning off the noise, the model would predict that these shocks would generate counterfactually large changes in the real economy in those two months.

[32] The sample mean over the period 2010-2022 is 6 percent. We choose to demean using 5 percent for consistency with the model calibration as well as the sample mean over the full sample. Results are robust to demeaning with 6 percent instead.

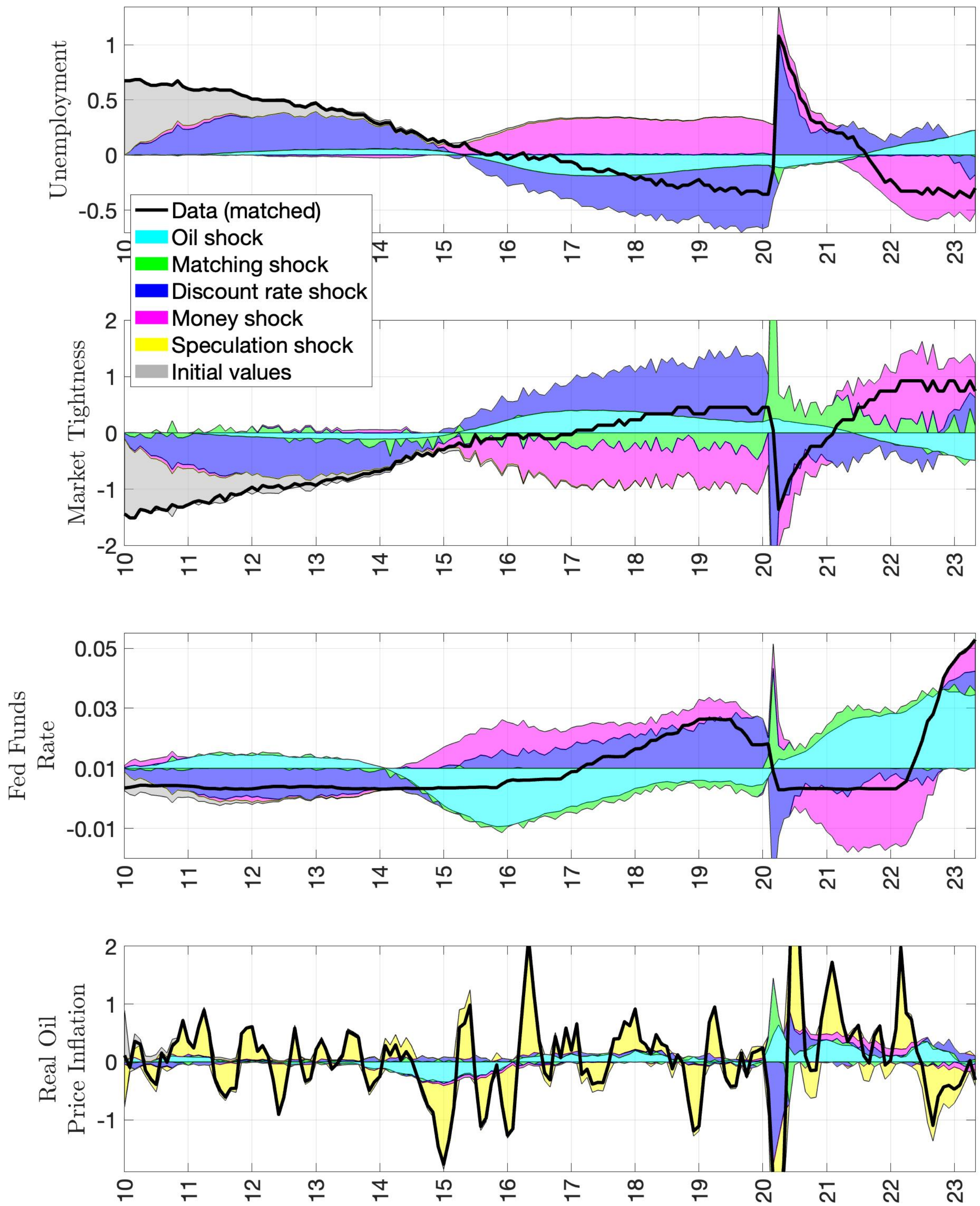

Figure 5: Historical shock decomposition of the targeted variables. Unemployment and labor market tightness are in log-deviations from the steady-state value for the model and log-deviations from the sample mean for the data. The decomposition for Fed funds is computed in deviations from steady state/sample mean and then rescaled up by the sample mean. Fed funds and oil inflation are annualized.

the sharp rise in unemployment during the pandemic as largely the product of a sharp drop in demand.[33] Unemployment then drops to steady state as demand improves. Interestingly, however, the drop in unemployment that continues in 2021-22 is largely the product of easy monetary policy. Indeed, over this period, monetary policy shocks more than offset the contractionary effect of oil shocks: from mid 2020 onward, oil shocks contribute a roughly two percentage point increase in unemployment.

The labor market mirrors the behavior of unemployment: it is highly sensitive to the demand shock until mid 2021. After that, accommodative monetary policy stimulates tightness, while oil shocks do the reverse. Interestingly, the matching shock is nontrivial during and after the pandemic but is not the leading driver of market tightness. It also does not materially contribute to unemployment variation over the sample.

The Federal Funds rate was fixed at the zero lower bound for much of the sample. The rise in the Funds rate just before the pandemic recession and the decline just after was largely in response to the rise and fall of the demand shock. From the end of 2020 to early 2022 the easy money shock keeps the funds rate low. After that, the oil shock is the main factor contributing to the tightening through its impact on inflation, as will become clear shortly.

After filtering out background noise with the speculation shock (as described earlier), the oil shock mainly drives the behavior of the oil price. The one exception is that the demand shock that pushed the economy into the pandemic recession placed significant downward pressure on oil prices.[34]

6.1.2 Untargeted Variables: Inflation and Wages

Figure 6 reports the shock decomposition for quarter-to-quarter annualized headline PCE inflation, core PCE inflation, nominal wage growth, and real wage growth.

The model tracks both PCE and core PCE inflation over the entire sample reasonably well. In particular, the model captures well the rise in core PCE inflation in 2021, the acceleration in early 2022, and the modest decline beginning in 2023. It understates the rise for a brief period in 2021, which can potentially be explained by

[33] As we show shortly, both headline and core PCE declined during the pandemic recession, consistent with the interpretation that the demand shock is an important driving force.

[34] Recent data on high-frequency oil shocks that extend the analysis by Känzig (2021) are consistent with the increase in oil prices being driven by a reduction in the OPEC oil supply in both 2021 and 2022. We thank Diego Känzig for sharing the updated series.

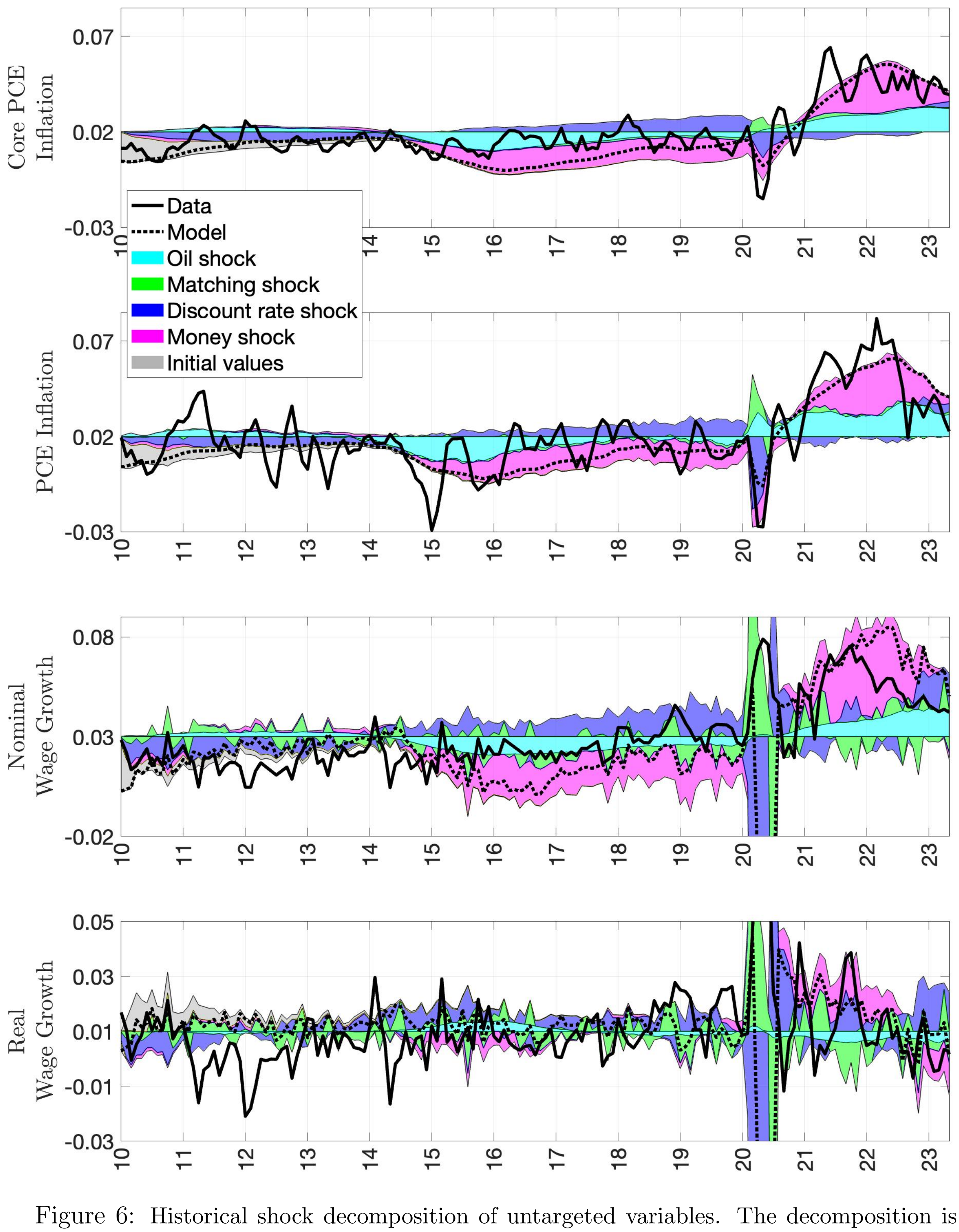

Figure 6: Historical shock decomposition of untargeted variables. The decomposition is computed in deviations from steady state/sample mean, and then rescaled up by the sample mean. All the variables are annualized.

the absence in the model of supply-chain factors.[35] Similarly, the model does also a good job at explaining the surge in quarter-to-quarter annualized headline inflation, though it misses part of the decline at the end of the sample, which is largely due to the drop in oil and commodity prices.

The decompositions also resolve a puzzle as to why inflation was low during the period 2014 to 2019 despite low unemployment, while high in recent years despite the same low unemployment level. In the former period, shocks that reduced oil prices in conjunction with tight money shocks helped keep inflation low. In the current period, just the opposite has happened: positive oil shocks in conjunction while easy money shocks have placed upward pressure on inflation. In addition, the decomposition shows why, despite high oil prices from 2010 to 2012, inflation remained low: at that time low demand in the wake of the Great Recession was keeping inflation down.

Interestingly, the matching shock does not contribute significantly to current inflation, consistently with its minimal impact on unemployment. As we noted earlier, market tightness does increase significantly over this period, but just about all of the increase is an endogenous response to other shocks.[36]

The model also tracks nominal and real product wage inflation reasonably well over the whole sample. It overstates nominal wage inflation after 2022:Q1, but it is reasonably on target for real wage growth, which is the relevant variable that enters the marginal cost and hence the relevant determinant of inflation in the model. There is one caveat due to a data issue, having to do with a large spike in wage inflation at the height of the pandemic recession in mid 2020 followed by a large reversal in the subsequent quarter. The likely cause of this spike was a compositional effect arising because employment losses were concentrated among low-wage workers. Our model of course cannot capture this kind of compositional effect.

We finally illustrate the mechanics of the inflation surge. As discussed in section 3, given that long-term inflation expectations are anchored, the only way the model can produce an inflation surge is to have a large persistent increase in the expected path of marginal cost. Indeed our model suggests just that: it implies that at the heart of the inflation surge in 2021 was a sharp increase in marginal cost. Figure 7

[35]Our interpretation of this evidence is consistent with Di Giovanni et al. (2022), which show that supply chain factors accounted for about a third of the inflation runup in the second half of 2021, but gave way to other forces in 2022.

[36]We checked that our results are robust to increase substantially the persistence of the matching shock to 0.9 and 0.95.

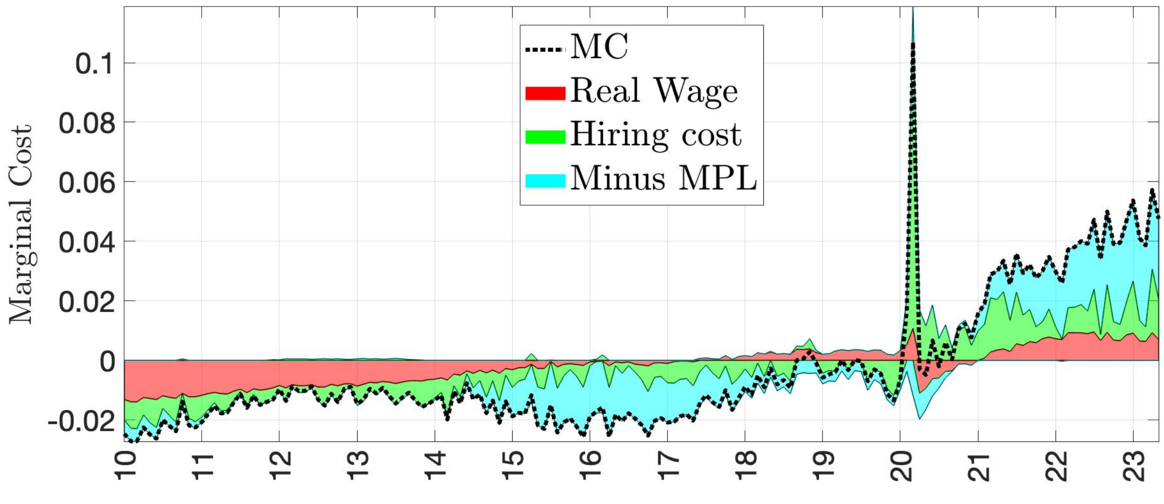

Figure 7: Historical decomposition of marginal cost into the main components from equation (24). Marginal cost is $\hat{p}_{wt}$, real wage is $\hat{w}_{qt}$ (multiplied by ζ), hiring cost is $\hat{\omega}_t$ (multiplied by $(1-\zeta)$), marginal product of labor is $\hat{a}_{nt}$ (multiplied by minus one).

shows the increase in marginal cost over this period and decomposes it into its three components: real wages, net hiring costs, and the marginal product of labor. As the figure shows, all three components play a role. However, the decline in the marginal product of labor accounts for more than half the increase. Given its importance in the dynamics of this variable, the strong complementarity between oil and labor plays an important role in the runup of marginal cost, and hence in the runup of inflation.

6.2 Accounting for forward guidance

Our approach thus far measures monetary policy accommodation by the deviation of the Federal Funds rate from what a conventional Taylor would predict. The delay in the liftoff of the Funds from the ZLB until early 2022 is then what leads us to assign an important role in the inflation surge to policy accommodation. A potential concern is that we ignore the tightening due to forward guidance that occurred prior to the Funds rate liftoff. Indeed government bond rates across the yield curve began to creep up in late 2021 prior to the liftoff, suggesting the tightening was in motion before this point. We will now show that our main results are robust to this consideration. Oil prices and monetary accommodation remain the most important factors in the inflation surge. However, the role of monetary accommodation dies out at the end of 2022. Demand (non-monetary) then assumes a nontrivial role in 2023 along with oil.

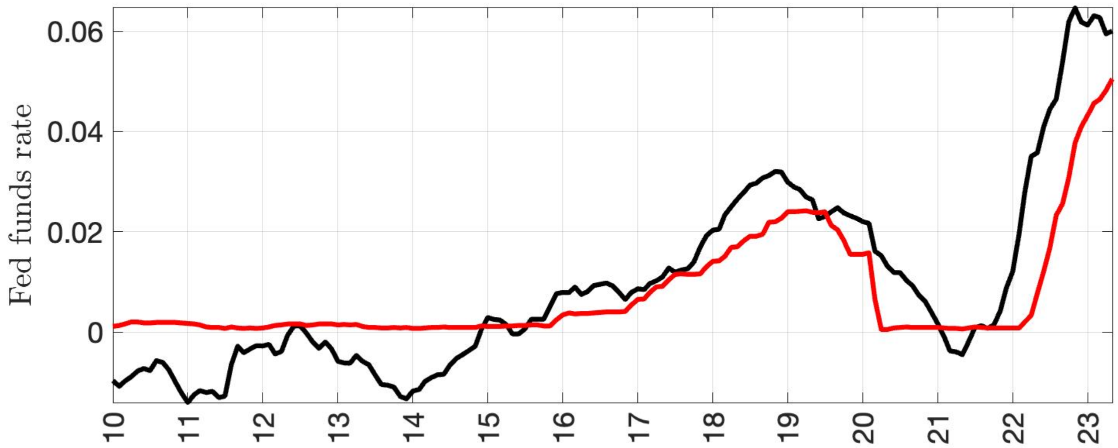

Figure 8: Comparison of the Fed funds rate (red) against the proxy rate (black).

We address this issue by making use of the "proxy" funds rate developed by Choi et al. (2022) that adjusts the funds rate to factor in the role of forward guidance and unconventional monetary policies. The authors first construct a financial conditions index based on the principal components of a set of long and short-term interest rates and interest rate spreads.[37] The proxy rate is then constructed as the fitted value of a regression of the effective funds rate on the index, with coefficients estimated on pre-2008 data. The idea is that, prior to 2008, the Federal Reserve did not rely significantly on either forward guidance or unconventional policies, so one can use this period to identify the correlation between the funds rate and the index absent these policies. Therefore, by construction, the proxy rate aligns closely with the funds rate before 2008. It differs after that to the extent that the long-term rates, which enter the index, are not aligned with the effective funds in the same way they were pre-2008. Therefore, any gap between the proxy rate and the funds rate post 2008 then reflects forward guidance and unconventional policies.

Figure 8 shows the proxy rate (black line) relative to the funds rate (red line) for the period 2010 to the present.[38] For periods where the ZLB is binding, the proxy rate moves below the funds rate. This likely reflects, among other things, the presence

[37]The interest rates include government bond rates on maturities ranging from two to ten years along with rates on private securities such as mortgages and corporate bonds. The spreads include both mortgage and corporate bond rates relative to similar-maturity government bond yields.

[38]We note that, by construction for the period prior to 2008, the proxy rate approximately coincides with the Fed funds rate.

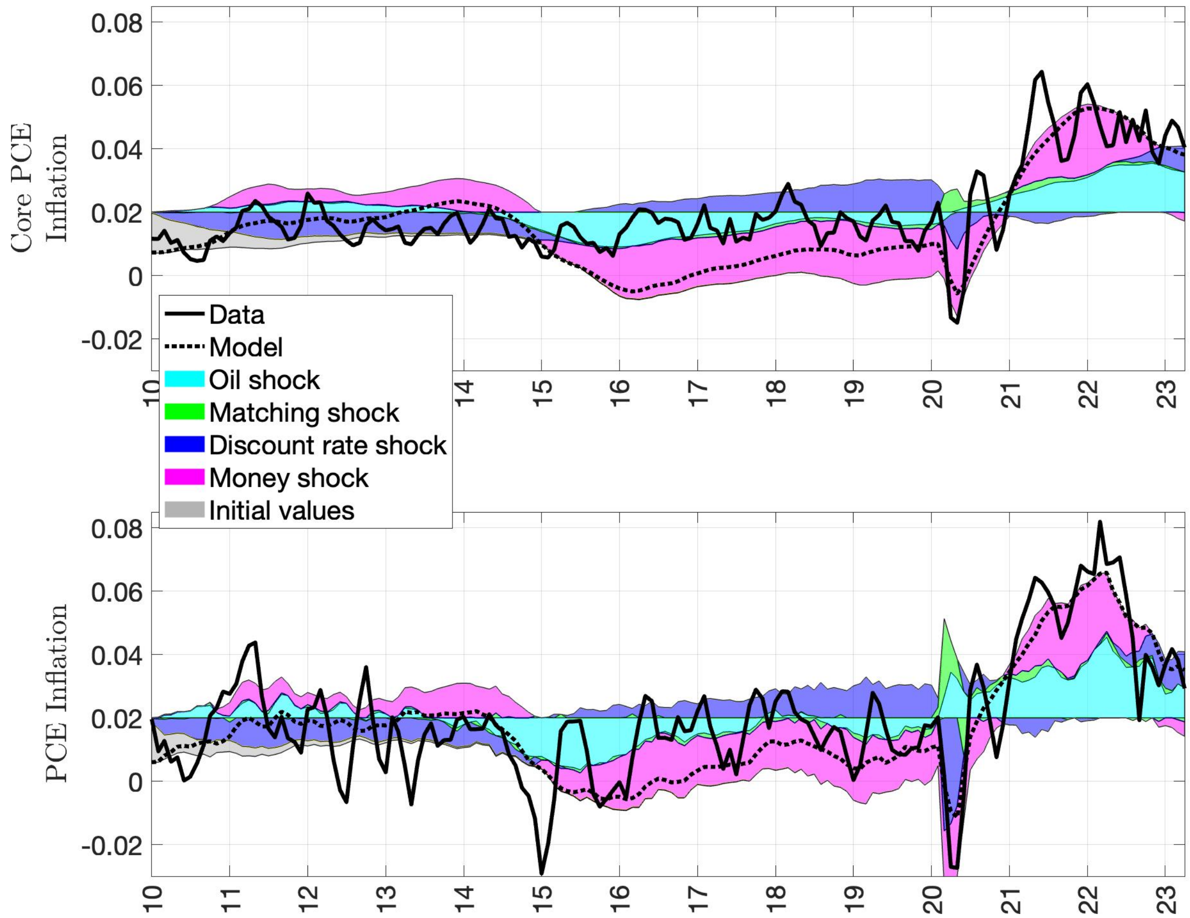

Figure 9: Historical decomposition when matching the proxy rate.

of longer maturity interest rates in the financial conditions index: during the ZLB periods, longer-term rates were lower than normal relative to the funds rate, due to forward guidance. Importantly for our purposes, over the recent tightening period, where long rates were high relative to the funds rate, the proxy rate leads the runup in funds rate by several months.

Accordingly, to account for the role of forward guidance in the recent tightening, we repeat the same accounting exercise as in section 6.1, but replace the funds rate with the proxy rate. Figure 9 reports the historical decomposition of core and headline inflation for the case with the proxy rate.[39] Interestingly, the ability of the model to explain the surge in both core and headline inflation rates improves a bit with respect to our baseline result. Beyond this, as before, oil prices and monetary accommodation are the main contributing factors to the surge. However, in contrast to the baseline,

[39]In Appendix C, we report the decompositions for the complete set of variables.

monetary accommodation dies out at the end of 2022, likely reflecting the impact of forward guidance. The demand shock then accounts for roughly a third of core PCE inflation in 2023 and the oil shock the remaining two thirds. For headline, demand and oil prices each account for about half.

7 Concluding Remarks

We have developed and estimated a simple New Keynesian model designed to account for the recent inflation surge. Among other things, the model features oil as a complementary good for households and as a complementarity input for firms. It also includes unemployment and real wage rigidity. We estimate the key parameters by matching model impulse responses to those from identified money and oil shocks in a structural VAR. We then show that our model does a good job of explaining unemployment and inflation since 2010, including the recent inflation surge that began in mid 2021 and has lasted through early 2023.

We show that mainly accounting for this surge was a combination oil price shocks and "easy" monetary policy, even after allowing for demand shocks and shocks to the labor market tightness. The main results are robust to accounting for policy tightening due to forward guidance which occurred prior to the liftoff of the Funds rate in early 2022. When accounting for forward guidance, the role of accommodative monetary policy for inflation dies out by the end of 2022. Oil and (non-monetary) demand shocks then almost entirely account for inflation in 2023.

Important for the quantitative impact of the oil price shock is that oil has a strong complementary role in both consumption and production in conjunction with real wage rigidity. Also important for explaining the data is that our model captures the persistent effects of oil and money shocks, which implies that these shocks have a significant impact on real and nominal variables well after they occur. We add that the model also helps account for why during the period 2010 to 2019 inflation was low despite low unemployment. At work was a series of oil price declines and money shocks, the exact opposite of what occurred during the recent inflation surge.

Finally, we have presumed that long-run inflation expectations have remained tightly anchored at the target as is consistent with the recent evidence. But how long we can count on inflation expectations remaining anchored as inflation persists in the three to four percent or above range is an important topic for future research.

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Online Appendix

A Estimation by Matching Impulse Response

In this section, we explain how the parameters are estimated and the confidence intervals are derived. In particular, we follow Hall et al. (2012) and Mertens and Ravn (2011) who propose an estimator based on the simulated method of moments and with inference based on the delta method. Specifically, let Λ^d be the $T \cdot N \cdot S$ vector of stacked impulse responses estimated in the data, where $T = 50$ is the forecast horizon in months, $N = 6$ the number of variables that are targeted, and $S = 2$ the number of shocks considered. Also, let $\Lambda^m(\Theta_2|\Theta_1)$ be the $T \cdot N \cdot S$ vector of stacked impulse responses obtained from model simulations, where Θ_2 is the set of parameters to be estimated conditional on the calibrated parameters Θ_1. Finally, let Σ_d^{-1}be a weighting matrix. The estimator of Θ_2 is given by:

$$\hat{\Theta}_2 = \arg\min_{\Theta_2} \left[\left(\Lambda^d - \Lambda^m(\Theta_2|\Theta_1)\right)' \Sigma_d^{-1} \left(\Lambda^d - \Lambda^m(\Theta_2|\Theta_1)\right) \right]$$

For the weighting matrix Σ_d^{-1}, we follow the standard approach to use the precision of the IRFs estimated from the VAR along the main diagonal, so that estimates with a smaller variance are assigned a larger weight in the minimization. We make an exception for the contemporaneous impact of the money shock on Fed Funds and the contemporaneous impact of the oil shock on the oil price, which we assign a larger weight to ensure these own impact moments are estimated more precisely.

The standard errors of $\hat{\Theta}_2$ are computed using an estimate of the asymptotic covariance matrix derived with the delta method:

$$\Sigma_{\Theta_2} = \Lambda_{\Theta_2} \frac{\partial \Lambda^m(\Theta_2|\Theta_1)'}{\partial \Theta_2} \Sigma_d^{-1} \Sigma_S \Sigma_d^{-1} \frac{\partial \Lambda^m(\Theta_2|\Theta_1)}{\partial \Theta_2} \Lambda_{\Theta_2}$$

where

$$\Lambda_{\Theta_2} = \left[\frac{\partial \Lambda^m(\Theta_2|\Theta_1)'}{\partial \Theta_2} \Sigma_d^{-1} \frac{\partial \Lambda^m(\Theta_2|\Theta_1)}{\partial \Theta_2} \right]^{-1}$$

$$\Sigma_S = \Sigma + \Sigma_s$$

and Σ denotes the covariance matrix of the estimated SVAR-based IRFs and Σ_s is the covariance matrix of the model-based impulse responses.

B Bayesian Estimation Result

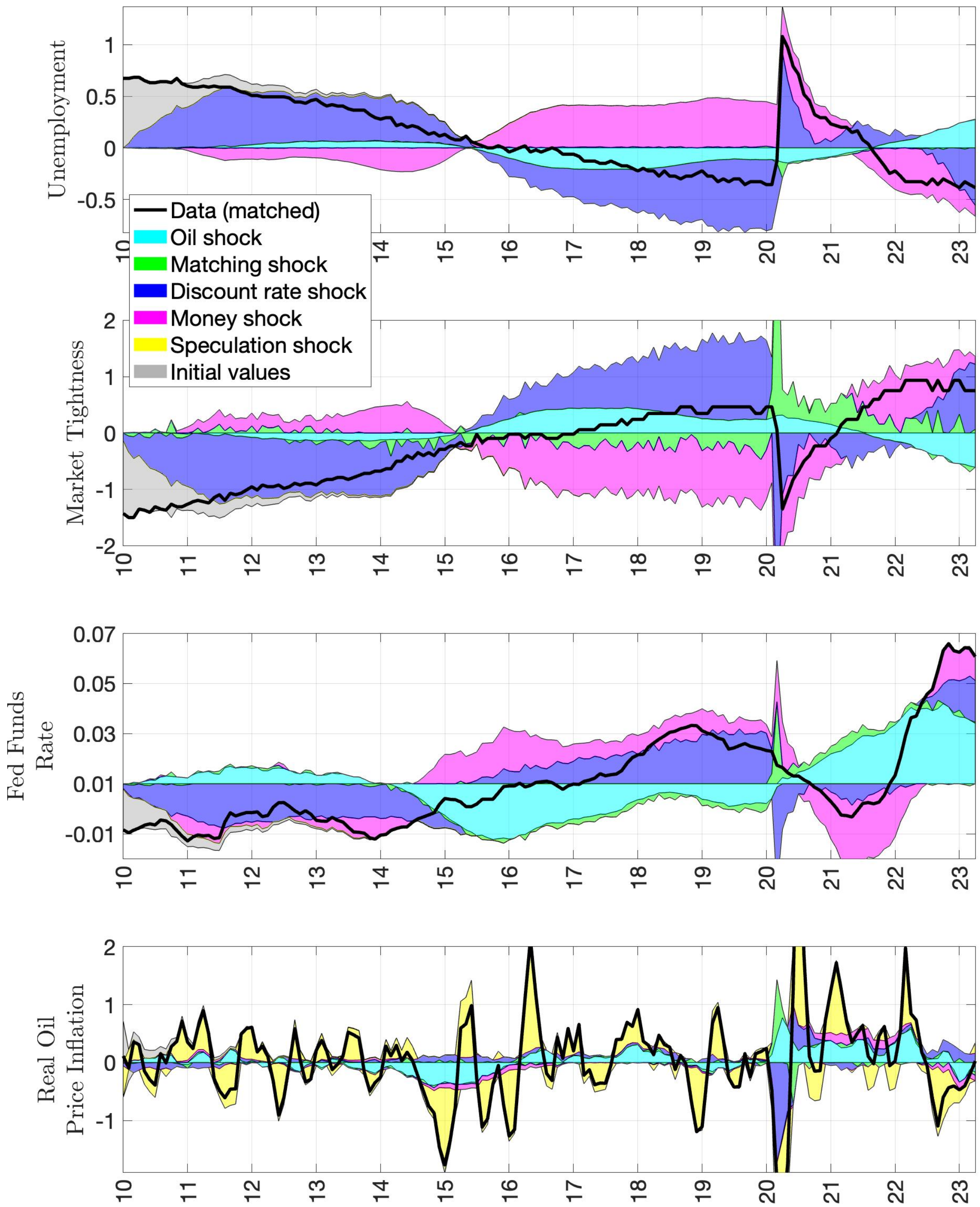
We report in Table 2 the results of the Bayesian estimation of the shocks over the sample 2010-2022.

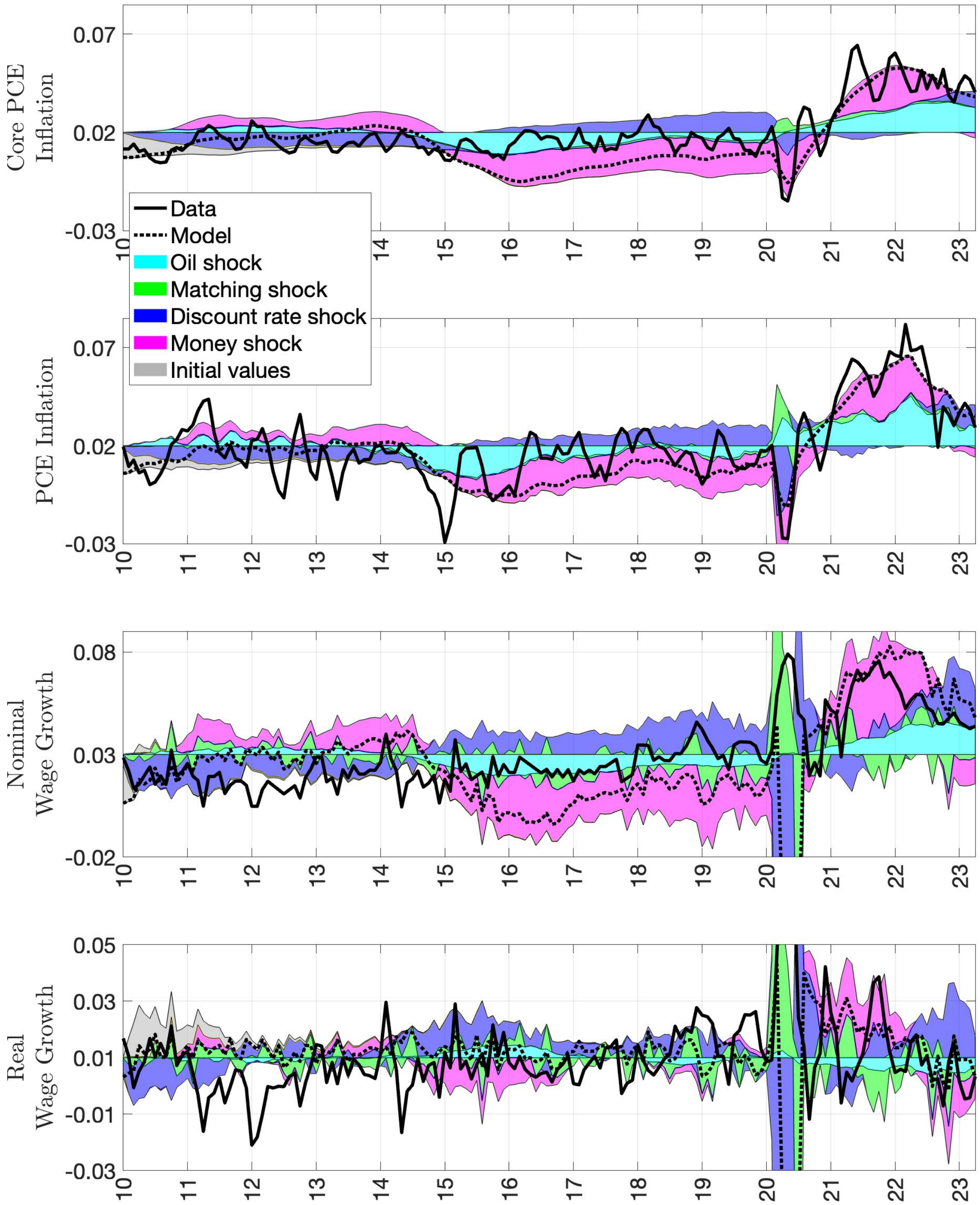
Parameter	Prior	Prior Mean	Prior stdev	Post. Mean	5%	95%
ρ^b	beta	.6	.1	.227	.177	.281
ρ^Φ	beta	.6	.1	.534	.432	.638
σ^b	invg	.15	.15	.061	.055	.066
σ^Φ	invg	.15	.15	.161	.145	.174
σ^m	invg	.15	.15	.248	.220	.281
σ^o	invg	.15	.15	.042	.035	.048
σ^r	invg	.15	.15	.038	.033	.043

Table 2: Bayesian estimation of the parameters over the sample 2010-2022.

Prior means and standard deviations are standard as in Primiceri et al. (2006). The prior standard deviations are sufficiently large to not impose serious restrictions on the parameters. The estimates imply that both the matching shock and the discount factor shock are not very persistent, with the matching shock more persistent ($\rho^\Phi = .53$ at the posterior mean) than the discount shock ($\rho^b = .23$ at the posterior mean). The estimates of the standard deviations are sensible, with the posterior means of the standard deviation for oil $\sigma^s = .04$ and money shock $\sigma^r = .04$ that are of the same order of magnitude as those estimated for the IRFs matching exercise (which were normalized to match one standard deviation of oil prices and Fed funds respectively). The mean of the standard deviation for the speculation shock $\sigma^m = .25$ is substantially larger than that of the oil shock, confirming the intuition that the speculation shock captures temporary volatility in oil prices that does not translate into a persistent effect on real variables. Finally, the posterior means for the matching shock $\sigma^\Phi = .16$ and discount factor shock $\sigma^b = .06$ are larger than both oil and money (because of the lower persistence), but of the same order of magnitude.

C Robustness with the proxy rate





Core PCE Inflation
PCE Inflation
Nominal Wage Growth
Real Wage Growth
Data
Model
Oil shock
Matching shock
Discount rate shock
Money shock
Initial values