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ABSTRACT

The central bank information (CBI) effect and the neo-Fisher effect produce similar outcomes: under both, a monetary tightening fails to reduce inflation and output. Separate estimates of these effects run the risk of confounding one with the other. To disentangle these two channels, we introduce into a new-Keynesian model, among other sources of fluctuations, a permanent monetary shock that generates neo-Fisher effects and a preference shock to which the central bank responds that creates CBI effects. We estimate the model on postwar quarterly U.S. data. We find that both effects are important: The neo-Fisher effect explains about one third of changes in inflation. And shutting down the Fed's direct response to the preference shock causes a doubling of the variance of inflation and a twenty percent increase in the variance of output. The results are robust to assuming that private agents have imperfect information, suggesting the presence of a central bank information channel, but the absence of a central bank information advantage, at least at quarterly frequency.

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1 Introduction

Central bank information (CBI) and neo-Fisher effects can occur simultaneously and can generate similar outcomes. Both can give rise to short-run increases in inflation and aggregate activity in response to a surprise increase in the policy interest rate. A natural question is what role do each of these mechanisms play in explaining why sometimes interest rates, prices, and quantities all move in the same direction after a monetary disturbance. In this paper, we provide an answer to this question from the perspective of a dynamic general equilibrium model estimated using postwar U.S. data.

We construct a model with nominal and real rigidities driven by permanent and transitory monetary shocks, two preference shocks, and permanent and transitory productivity shocks. To create a central bank information channel, we assume an augmented Taylor rule whereby the central bank responds directly to one of the preference shocks in addition to the output gap and inflation. To create a neo-Fisher effect, we assume that the Taylor rule is also buffeted by permanent monetary shocks in addition to standard transitory monetary shocks.

We examine two polar information structures: in one, private agents observe all shocks individually, while in the other, agents observe only the sum of the two preference shocks and the stochastic component of the Taylor rule, but not the individual shocks that compose them.

We find that both the neo-Fisher and central bank information effects are important drivers of macroeconomic indicators of interest: Permanent monetary shocks explain between 20 and 30 percent of the variance of inflation changes. And when we shut down the response of the central bank to the preference shock, the variance of inflation changes doubles and the variance of output growth increases by 20 percent. The standard monetary shock plays a minor role in accounting for movements in interest rates, inflation, and output.

These results hold under both full and imperfect information, indicating that while a significant central bank information effect is present (the central bank observes and responds directly to a real shock), there is no evidence of a central bank information advantage, at least at the quarterly frequency. The reason why imperfect information does not seem to be empirically important is that, although CBI and neo-Fisher shocks can generate similar short-run outcomes, their dynamic implications differ markedly, allowing agents to rapidly distinguish between them. The results are also robust to including high-frequency monetary shocks and long-term yields as observables in the estimation.

To the best of our knowledge, this paper is the first attempt to evaluate jointly the contributions of the neo-Fisher effect, the central bank information channel, and the central bank information advantage channel. It is related to two strands of the recent monetary literature, one dedicated to the neo-Fisher effect and the other to the central bank information effect. The formulation and estimation of the neo-Fisher effect in the context of an optimizing model adopted in this study follows Uribe (2022). The neo-Fisher effect has been estimated in the context of empirical models among others by Uribe (2017, 2022) and Valle e Azevedo, Ritto, and Teles (2022) using data from advanced countries, García-Cicco, Goldstein, and Sturzenegger (2024) using data from advanced and emerging economies, and Schmitt-Grohé and Uribe (2022) and Carvalho, Valle e Azevedo, and Pires Ribeiro (2024) in open-economy settings. Lukmanova and Rabitsch (2023) estimate the neo-Fisher effect in the context of an equilibrium model with transitory but persistent monetary shocks and imperfect information. These studies find evidence of a significant neo-Fisher effect, that is, they find that a permanent or highly persistent innovation in the interest rate raises inflation and aggregate activity in the short run. Theoretical formulations of the neo-Fisher effect can be found in Schmitt-Grohé and Uribe (2010, 2012), Cochrane (2016), Williamson (2016), and Garín, Lester, and Sims (2018).

There is a large literature studying the central bank information effect. Romer and Romer (2000), Barakchian and Crowe (2013), and Campbell, Fisher, Justiniano, and Melosi (2017) provide early evidence of a central bank information advantage. Estimates of the central bank information shock include Hansen and McMahon (2016) using language analysis of central bank announcements, Kerssenfischer (2022), Cieslak and Schrimpf (2019), and Jarociński and

Karadi (2020) using high frequency movements in stock prices, Miranda-Agrippino (2016) and Campbell, Fisher, Justiniano, and Melosi (2017) using forecast differentials between the private sector and the Federal Reserve, Acosta (2023) using textual analysis of newspaper articles around FOMC announcements, and García-Schmidt (2024) using data from forecasts of inflation and output growth from emerging countries. The macroeconomic effects of CBI shocks have been studied in Melosi (2017), Nakamura and Steinsson (2018), and Jarociński and Karadi (2020). Finally, there are studies that have raised questions about the neo-Fisher and CBI channels. See García-Schmidt and Woodford (2019) and Bouakez and Kano (2024) for papers questioning the neo-Fisher effect and Faust, Swanson, and Wright (2004) and Bauer and Swanson (2023) for papers challenging the CBI advantage channel.

The present study connects the two branches of the monetary economics literature just described by assessing jointly the contributions of shocks that generate neo-Fisher and CBI effects. It shows that both channels remain significant when put to compete for the data. It also clarifies and quantifies the distinction between a CBI channel and a CBI advantage channel, estimating that the former is quantitatively important, whereas the latter is not.

The remainder of the paper is organized as follows. Section 2 presents the proposed model. Section 3 discusses the econometric estimation. Section 4 presents the results. Section 5 concludes.

2 The Model

The model economy features sticky prices, habit formation, permanent and transitory monetary shocks, permanent and transitory productivity shocks, and preference shocks.

2.1 Households

The economy is populated by households with preferences defined over streams of consumption and labor effort and exhibiting external habit formation. The household's lifetime utility function is

$$E_0 \sum_{t=0}^{\infty} \beta^t e^{\xi_t} \left\{ \frac{\left[(C_t - \delta \widetilde{C}_{t-1})(1 - e^{\theta} h_t)^{\chi}\right]^{1-\sigma} - 1}{1-\sigma} \right\}, \tag{1}$$

where C_t denotes consumption, $\widetilde{C}_t$ denotes the cross-sectional average of consumption, h_t denotes hours worked, ξ_t is a preference shifter, δ is a parameter governing the degree of habit formation, $\beta \in (0,1)$ is the subjective discount factor, and $\sigma, \chi > 0$ and θ are parameters. The symbol E_t denotes the expectations operator conditional on information available to the household at time t.

To model a central bank information channel, we assume that the preference shifter ξ_t is the sum of two exogenous and stochastic components,

$$\xi_t = \xi_t^h + \xi_t^c. \tag{2}$$

The central bank is assumed to observe ξ_t^c and to respond to it in setting the nominal interest rate. To distinguish the CBI channel from the CBI advantage channel, we consider two information structures, full information and imperfect information. Under full information, private agents observe all shocks. In particular, they observe ξ_t^h and ξ_t^c. Under imperfect information, private agents are assumed to observe combinations of shocks, but not all shocks individually. In particular, they observe the preference shifter ξ_t, but not its individual components ξ_t^h and ξ_t^c.

Households are subject to the budget constraint

$$P_t C_t + \frac{B_t}{1+I_t} + T_t = B_{t-1} + W_t h_t + \Phi_t, \tag{3}$$

where P_t denotes the price level, T_t denotes nominal lump-sum taxes, W_t denotes the nominal wage rate, and Φ_t denotes nominal profits received from firms. The variable B_t denotes the units of a one-period nominal discount bond purchased in period t that pays the interest rate I_t.

The consumption good C_t is assumed to be a composite of a continuum of varieties C_{it} indexed by $i \in [0, 1]$ with aggregation technology

$$C_t = \left[\int_0^1 C_{it}^{1-1/\eta} di \right]^{\frac{1}{1-1/\eta}}, \tag{4}$$

where the parameter $\eta > 0$ denotes the elasticity of substitution across varieties.

Households choose processes $\{C_t, h_t, B_t\}_{t=0}^{\infty}$ to maximize the utility function (1) subject to the budget constraint (3) and to some borrowing limit that prevents them from engaging in Ponzi schemes. Letting $\beta^t \Lambda_t / P_t$ denote the Lagrange multiplier associated with the budget constraint (3), the first-order conditions of the household's optimization problem are

$$e^{\xi_t}(C_t - \delta \widetilde{C}_{t-1})^{-\sigma}(1 - e^{\theta} h_t)^{\chi(1-\sigma)} = \Lambda_t, \tag{5}$$

$$\frac{\chi e^{\theta}(C_t - \delta \widetilde{C}_{t-1})}{1 - e^{\theta} h_t} = \frac{W_t}{P_t}, \tag{6}$$

and

$$\Lambda_t = \beta(1 + I_t) E_t \left[\frac{\Lambda_{t+1}}{1 + \Pi_{t+1}} \right], \tag{7}$$

where $\Pi_t \equiv P_t / P_{t-1} - 1$ denotes the inflation rate in period t.

Given its desired level of consumption, C_t, the household chooses the consumption of varieties C_{it} to minimize total expenditure, $\int_0^1 P_{it} C_{it} di$, subject to the aggregation technology (4), where P_{it} denotes the nominal price of variety i. This problem delivers the following demand for individual varieties:

$$C_{it} = C_t \left(\frac{P_{it}}{P_t} \right)^{-\eta}, \tag{8}$$

where the price level P_t satisfies

$$P_t \equiv \left[\int_0^1 P_{it}^{1-\eta} di \right]^{\frac{1}{1-\eta}} \tag{9}$$

and represents the minimum cost of one unit of the composite consumption good, C_t.

2.2 Firms

The firm producing variety i operates in a monopolistically competitive market and faces quadratic price adjustment costs à la Rotemberg (1982). The production technology uses labor and is buffeted by transitory and permanent productivity shocks. Specifically, output of variety i is given by

$$Y_{it} = e^{z_t} \Omega_t h_{it}^{\alpha}, \tag{10}$$

where Y_{it} denotes output of variety i in period t, h_{it} denotes labor input used in the production of variety i, z_t is a stationary productivity shock, and Ω_t is a nonstationary productivity shock. The growth rate of Ω_t is assumed to be a stationary random variable with mean g,

$$\ln \left(\frac{\Omega_t}{\Omega_{t-1}} \right) = g_t + g,$$

where g_t is stationary and has mean 0.

The expected present discounted value of real profits of the firm producing variety i expressed in units of the final good is given by

$$E_0 \sum_{t=0}^{\infty} q_t \left[\frac{P_{it}}{P_t} A_{it} - \frac{W_t}{P_t} h_{it} - \frac{\phi}{2} \Omega_t \left(\frac{P_{it}/P_{it-1}}{1+\widetilde{\Pi}_t} - 1 \right)^2 \right], \tag{11}$$

where A_{it} denotes the total demand for good i, $\phi > 0$ is a parameter governing the degree of price rigidity, and $q_t \equiv \beta^t \Lambda_t / \Lambda_0$ denotes a pricing kernel reflecting the assumption that firms are owned by households. Price adjustment costs are defined in units of the final good and are scaled by the trend component of productivity Ω_t to keep nominal rigidity from vanishing along the balanced growth path. The total demand for good i, A_{it}, includes the demand stemming from households and the demand stemming from firms to cover their price adjustment costs. Specifically, the demand for good i is given by

$$A_{it} = A_t \left(\frac{P_{it}}{P_t} \right)^{-\eta} \tag{12}$$

with

$$A_t = C_t + \frac{\phi}{2} \Omega_t \int_0^1 \left(\frac{P_{jt}/P_{jt-1}}{1 + \widetilde{\Pi}_t} - 1 \right)^2 dj. \tag{13}$$

The second term of this expression is nil up to first order. The variable $\widetilde{\Pi}_t$ denotes the average level of inflation around which price-adjustment costs are defined. It is predetermined in period t and is assumed to evolve over time according to

$$1 + \widetilde{\Pi}_{t+1} = (1 + \widetilde{\Pi}_t)^{\gamma_\pi} (1 + \Pi_t)^{1-\gamma_\pi}, \tag{14}$$

where the parameter $\gamma_\pi \in [0, 1]$ governs the backward-lookingness of price indexation.

The problem of the firm producing variety i is to choose processes $\{P_{it}, A_{it}, Y_{it}, h_{it}\}_{t=0}^{\infty}$ to maximize (11) subject to the demand equation (12), the production technology (10), and the requirement that demand be satisfied at the price set by the firm,

$$Y_{it} \geq A_{it}, \tag{15}$$

taking as given the processes $\widetilde{\Pi}_t$, z_t, Ω_t, A_t, W_t, P_t, and q_t.

Letting $q_t mc_{it}$ be the Lagrange multiplier associated with the demand constraint (15), the first-order conditions of the firm's profit maximization problem are

$$mc_{it} = \frac{W_t/P_t}{\alpha e^{z_t} \Omega_t h_{it}^{\alpha-1}} \tag{16}$$

and

$$\eta A_{it}\left(\frac{\eta-1}{\eta}\frac{P_{it}}{P_t}-mc_{it}\right)=-\phi\Omega_t\frac{P_{it}/P_{it-1}}{1+\widetilde{\Pi}_t}\left(\frac{P_{it}/P_{it-1}}{1+\widetilde{\Pi}_t}-1\right)+\phi E_t\frac{q_{t+1}}{q_t}\Omega_{t+1}\frac{P_{it+1}/P_{it}}{1+\widetilde{\Pi}_{t+1}}\left(\frac{P_{it+1}/P_{it}}{1+\widetilde{\Pi}_{t+1}}-1\right). \tag{17}$$

The first of these optimality conditions says that the multiplier mc_{it} represents the firm's marginal cost. The second optimality condition states that, all else equal, if marginal revenue, $\frac{\eta-1}{\eta}\frac{P_{it}}{P_t}$, exceeds marginal cost, mc_{it}, then the firm will raise its price at a rate below the normal trend, $P_{it}/P_{it-1} < 1+\widetilde{\Pi}_t$; conversely, if marginal revenue falls short of marginal cost, the firm will raise its price at a rate above the normal trend.

2.3 Monetary and Fiscal Policy

The monetary authority follows a Taylor-type interest-rate feedback rule buffeted by a stationary monetary shock denoted z_t^m and a nonstationary monetary shock denoted X_t^m. The nonstationary monetary shock X_t^m is meant to capture the neo-Fisher effect (Uribe, 2022). The monetary rule also includes a central bank information channel. Specifically, the monetary authority is assumed to respond to the exogenous preference shifter ξ_t^c. Formally, monetary policy is defined by the expression

$$\frac{1+I_t}{X_t^m}=\left[\Gamma\left(\frac{1+\Pi_t}{X_t^m}\right)^{\alpha_\pi}\left(\frac{Y_t}{Y_t^n}\right)^{\alpha_y}\right]^{1-\gamma_I}\left(\frac{1+I_{t-1}}{X_{t-1}^m}\right)^{\gamma_I}e^{z_t^m+\alpha_\xi\xi_t^c}, \tag{18}$$

where Y_t denotes aggregate output, Y_t^n denotes the flexible-price or natural level of output, and Γ, α_π, α_y, α_ξ, and $\gamma_I \in [0,1)$ are parameters. The parameter α_ξ defines the central bank information channel. The growth rate of the nonstationary monetary shock,

$$g_t^m \equiv \ln\left(\frac{X_t^m}{X_{t-1}^m}\right),$$

is assumed to be stationary.

As mentioned early, we distinguish between the CBI effect and the CBI advantage effect.

The CBI effect is captured by the assumption that the central bank observes the nonmonetary shock ξ_t^c and responds to it directly with policy coefficient α_ξ. The CBI advantage effect is captured by considering two alternative information structures. Under full information, households and firms observe all components of the Taylor rule, including the exogenous shocks, that is, they observe the nominal interest rate, I_t, inflation, Π_t, the output gap, Y_t/Y_t^n, and the exogenous shocks X_t^m, z_t^m, and ξ_t^c. By contrast, under imperfect information, households and firms are assumed to observe I_t, Π_t, Y_t/Y_t^n, and the exogenous stochastic component of the Taylor rule, which we denote $\widetilde{\Omega}_t^m$, and which is given by

$$\widetilde{\Omega}_t^m \equiv X_t^{m\,1-\alpha_\pi(1-\gamma_I)} X_{t-1}^{m}{}^{-\gamma_I} e^{z_t^m + \alpha_\xi \xi_t^c}. \tag{19}$$

Thus, under imperfect information, households and firms are assumed to be unable to observe the individual components of $\widetilde{\Omega}_t^m$, namely, X_t^m, z_t^m, and ξ_t^c.

Government consumption is assumed to be nil at all times. The government's budget constraint is then given by

$$T_t + \frac{B_t}{1+I_t} = B_{t-1}.$$

Fiscal policy is assumed to be Ricardian, that is, the path of lump-sum taxes, T_t, guarantees the intertemporal solvency of the government independently of the path of the price level.

2.4 Driving Forces

The structural shocks driving the economy, ξ_t^h, ξ_t^c, z_t^m, g_t^m, g_t, and z_t are assumed to follow AR(1) processes of the form

$$x_t = \rho_x x_{t-1} + \sigma_x \epsilon_t^x, \tag{20}$$

where ϵ_t^x is an i.i.d. random disturbance distributed $N(0,1)$, $\rho_x \in [0,1)$ is the serial correlation of x_t, and $\sigma_x \geq 0$ is the standard deviation of the innovation of the process, for $x = \xi^h$, ξ^c, z^m, g^m, g, and z.

2.5 Market Clearing

Clearing of the labor market requires that the demand for labor by firms equal the household's supply of labor,

$$\int_0^1 h_{it} di = h_t. \tag{21}$$

Because all households are identical, so are individual and aggregate consumption per capita,

$$C_t = \widetilde{C}_t.$$

We focus attention on a symmetric equilibrium in which all firms charge the same nominal price and employ the same amount of labor, that is, an equilibrium in which h_{it} and P_{it} are the same for all $i \in [0, 1]$. We then have from equations (8), (9), (10), (16), and (21) that $P_{it} = P_t$, $C_{it} = C_t$, $h_{it} = h_t$, $mc_{it} = mc_t$, and $Y_{it} = e^{z_t}\Omega_t h_t^\alpha$, for all i. Output measured in units of the final good is then given by $Y_t \equiv \left(\int_0^1 P_{it} Y_{it} di\right) / P_t = e^{z_t}\Omega_t h_t^\alpha$. As long as the nominal wage is positive, the firm will choose to satisfy the demand constraint (15) with equality, so that in equilibrium

$$Y_t = C_t + \frac{\phi}{2}\Omega_t \left(\frac{1+\Pi_t}{1+\widetilde{\Pi}_t} - 1\right)^2.$$

2.6 Equilibrium Conditions in Stationary Form

The model is driven, among other sources of variation, by two nonstationary shocks, the nonstationary productivity shock, Ω_t, and the nonstationary monetary shock, X_t^m. We express the model in terms of stationary variables by scaling all variables with stochastic trends by their respective permanent components. Under imperfect information, however, the choice of these trend components is nontrivial. The reason is that all conditional expectations in the model are taken given the information set of the private agents (households and firms), which in period t, under imperfect information, includes the nonstationary productivity shock Ω_t, but not the nonstationary monetary shock X_t^m. Thus, Ω_t can be used as a scaler to transform nonstationary real variables into stationary real variables, but X_t^m cannot be used in a similar way to transform nonstationary nominal variables into stationary ones.

To illustrate the problem with using X_t^m to transform nonstationary nominal variables into stationary ones under imperfect information, consider a generic expression of the form $N_t^1 = E_t N_{t+1}^2$, where N_t^1 and N_t^2 are two nominal variables cointegrated with X_t^m. Under full information we could use X_t^m as a scaler and define $n_t^1 = N_t^1/X_t^m$ and $n_t^2 = N_t^2/X_t^m$. Because under full information $1/X_t^m E_t N_{t+1}^2 = E_t N_{t+1}^2/X_t^m$, we can write $n_t^1 = E_t \left[n_{t+1}^2 e^{g_{t+1}^m} \right]$, which, as desired, includes only stationary variables. However, if X_t^m is not in the period-t information set of private agents, then $1/X_t^m E_t N_{t+1}^2 \neq E_t N_{t+1}^2/X_t^m$, rendering this approach to induce stationarity infeasible.

Therefore, in order to transform nonstationary nominal variables into stationary ones, we must use an object that is observable in period t by private agents and is cointegrated with X_t^m with cointegration vector $[1\ -1]$.[1] A suitable transformation of the variable $\widetilde{\Omega}_t^m$ defined in equation (19) satisfies this requirement. To see this, note first that by assumption $\widetilde{\Omega}_t^m$ is in the information set of private agents in period t. Second, note that the exponents of X_t^m and X_{t-1}^m in the definition of $\widetilde{\Omega}_t^m$ in equation (19) add up to $(1-\alpha_\pi)(1-\gamma_I)$. It follows that the suitable transformation of $\widetilde{\Omega}_t^m$, which we denote Ω_t^m, is

$$\Omega_t^m \equiv \left(\widetilde{\Omega}_t^m\right)^{\frac{1}{(1-\alpha_\pi)(1-\gamma_I)}}.$$

Accordingly, we use the observable exogenous variables Ω_t and Ω_t^m as the scalers to convert, respectively, real and nominal nonstationary variables into stationary variables. Specifically, we create the stationary variables $c_t \equiv C_t/\Omega_t$, $y_t \equiv Y_t/\Omega_t$, $y_t^n \equiv Y_t^n/\Omega_t$, $a_t \equiv A_t/\Omega_t$, $w_t \equiv W_t/(P_t\Omega_t)$, $\lambda_t \equiv \Lambda_t \Omega_t^\sigma$, $1+\pi_t \equiv (1+\Pi_t)/\Omega_t^m$, $1+i_t \equiv (1+I_t)/\Omega_t^m$, and

[1] One might think that a possible candidate could be a lagged value of X_t^m. However, under imperfect information X_{t-j}^m is not in the period-t information set of private agents for any $j \geq 0$.

$1+\widetilde{\pi}_t \equiv (1+\widetilde{\Pi}_t)/\Omega^m_{t-1}$. Let $g^{\omega m}_t \equiv \ln\left(\frac{\Omega^m_t}{\Omega^m_{t-1}}\right)$ be the growth rate of Ω^m_t, so that

$$g^{\omega m}_t = \frac{g^m_t[1-\alpha_\pi(1-\gamma_I)] - g^m_{t-1}\gamma_I + z^m_t - z^m_{t-1} + \alpha_\xi(\xi^c_t - \xi^c_{t-1})}{(1-\alpha_\pi)(1-\gamma_I)}. \tag{22}$$

We can then write equilibrium conditions (5)–(7), (10), and (13)–(18), respectively, in stationary form as

$$\lambda_t = e^{\xi_t}\left(c_t - \delta\frac{c_{t-1}}{e^{g_t+g}}\right)^{-\sigma}\left(1-e^{\theta}h_t\right)^{\chi(1-\sigma)}, \tag{23}$$

$$\frac{\chi e^{\theta}\left(c_t - \delta\frac{c_{t-1}}{e^{g_t+g}}\right)}{1-e^{\theta}h_t} = w_t, \tag{24}$$

$$\lambda_t = \beta(1+i_t)E_t\left[\frac{\lambda_{t+1}}{1+\pi_{t+1}}e^{-g^{\omega m}_{t+1}-\sigma(g_{t+1}+g)}\right], \tag{25}$$

$$y_t = e^{z_t}h^{\alpha}_t, \tag{26}$$

$$a_t = c_t + \frac{\phi}{2}\left(\frac{1+\pi_t}{1+\widetilde{\pi}_t}e^{g^{\omega m}_t} - 1\right)^2, \tag{27}$$

$$1+\widetilde{\pi}_{t+1} = [(1+\widetilde{\pi}_t)e^{-g^{\omega m}_t}]^{\gamma_m}(1+\pi_t)^{1-\gamma_m}, \tag{28}$$

$$y_t = a_t, \tag{29}$$

$$\mathrm{mc}_t = \frac{w_t}{\alpha e^{z_t}h^{\alpha-1}_t}, \tag{30}$$

$$\left(\frac{\eta-1}{\eta}-mc_t\right)a_t = \frac{\phi}{\eta}\beta E_t e^{(1-\sigma)(g_{t+1}+g)}\frac{\lambda_{t+1}}{\lambda_t}\frac{1+\pi_{t+1}}{1+\widetilde{\pi}_{t+1}}e^{g^{\omega m}_{t+1}}\left(\frac{1+\pi_{t+1}}{1+\widetilde{\pi}_{t+1}}e^{g^{\omega m}_{t+1}}-1\right)$$
$$-\frac{\phi}{\eta}\frac{1+\pi_t}{1+\widetilde{\pi}_t}e^{g^{\omega m}_t}\left(\frac{1+\pi_t}{1+\widetilde{\pi}_t}e^{g^{\omega m}_t}-1\right), \qquad (31)$$

and

$$1+i_t=\left[\Gamma(1+\pi_t)^{\alpha_\pi}\left(\frac{y_t}{y^n_t}\right)^{\alpha_y}\right]^{1-\gamma_I}\left(\frac{1+i_{t-1}}{e^{g^{\omega m}_t}}\right)^{\gamma_I}. \qquad (32)$$

The detrended flexible-price level of output, y^n_t, is given by the solution of equations (24), (26), and (30) evaluated at $c_t = y^n_t$ and $mc_t = (\eta-1)/\eta$, for all t. This yields y^n_t implicitly as

$$\frac{\chi e^{\theta}\left(y^n_t-\delta\frac{y^n_{t-1}}{e^{g_t+g}}\right)}{1-e^{\theta}(y^n_t e^{-z_t})^{1/\alpha}}=\frac{\eta-1}{\eta}\alpha e^{z_t/\alpha}\left(y^n_t\right)^{(\alpha-1)/\alpha}. \qquad (33)$$

Note that y^n_t depends on the productivity shocks z_t and g_t, but not on preference or monetary shocks, so it is observable to private agents even under imperfect information. Finally, note that Ω^m_t is a valid scaler to induce stationarity not only under imperfect information, but also under full information, since it is clearly in the information set of private agents in the latter environment.

We are ready to define a competitive equilibrium under full and incomplete information:

Definition 1 (Equilibrium) *An equilibrium is a set of processes c_t, h_t, λ_t, w_t, i_t, π_t, $\tilde{\pi}_t$, y_t, y^n_t, a_t, mc_t, $g^{\omega m}_t$, and ξ_t satisfying (2) and (22)–(33), given stochastic processes ξ^h_t, ξ^c_t, z_t, g_t, z^m_t, and g^m_t, and the initial conditions c_{-1}, y^n_{-1}, $\tilde{\pi}_0$, i_{-1}, g^m_{-1}, z^m_{-1}, and ξ^c_{-1}. Under full information private agents observe the realizations of all six exogenous shocks, whereas under imperfect information agents observe realizations of ξ_t, $g^{\omega m}_t$, z_t, and g_t.*

We approximate the equilibrium dynamics up to first-order accuracy. For the case of full information, the technique for solving linearized rational expectations models is standard. In Appendix A, we explain how to solve for the rational expectations equilibrium under imperfect information.

Table 1: Calibrated Parameters

Parameter	Value	Description
g	0.0041	mean output growth rate
σ	2	inverse of intertemp. elast. subst.
β	0.9982	subjective discount factor
η	6	intratemporal elast. of subst.
α	0.75	labor semielast. of output
θ	0.4055	preference parameter

Note. The time unit is one quarter.

We now proceed to estimate the model and characterize its equilibrium properties.

3 Estimation

We follow the standard practice of calibrating some parameters and estimating others. We estimate the parameters defining all stochastic processes, the parameters defining price stickiness and habit formation, and all policy parameters. The remaining parameters are calibrated.

Table 1 summarizes the calibration. The time unit is one quarter. The calibrated parameters take standard values in business-cycle analysis. We set the steady-state of the growth rate of the nonstationary productivity shock, g, to 0.0041, which is consistent with an average growth rate of output per capita of about 1.7 percent per year over the postwar period; the inverse of the intertemporal elasticity of consumption substitution, σ, to 2; the steady-state real interest rate to 4 percent per year, which implies a growth-adjusted discount factor, $\beta e^{-\sigma g}$, of 0.99 per year and a value of β of 0.9982; the labor elasticity of output, α, to 0.75; the elasticity of substitution across good varieties, η, to 6; the steady-state share of time allocated to work, h, to 1/3; and the labor supply elasticity holding consumption constant, $(1-e^{\theta}h)/(e^{\theta}h)$, to 1. The last two restrictions imply that the preference parameter θ equals $-\ln(2h) = 0.4055$. These two restrictions in combination with value for the habit parameter δ, to be estimated below, deliver an estimate of the preference parameter χ.

We estimate the remaining parameters under full and imperfect information using Bayesian techniques. The estimation uses quarterly U.S. data covering the period 1961:Q3 to 2019:Q4. We leave the Covid-19 years out of the sample as they were arguably driven by extraordinary shocks not included in the model. The data used in the estimation contains observations on the growth rate of real GDP per capita, $\Delta \ln Y_t$, the change in the nominal interest rate, proxied by the Federal Funds rate, ΔI_t, and the interest-rate inflation differential, $I_t - \Pi_t$, where Π_t is proxied by the growth rate of the implicit GDP deflator. In section 4.3, we expand the set of observables to include a monetary shock constructed from high frequency information and in section 4.4 we incorporate data on long-maturity bond yields. The results reported below are based on a random subsample of 1 million draws from an MCMC chain of length 50 million constructed by using the Metropolis-Hastings sampler.

Table 2 provides a summary of the prior and posterior distributions of the estimated parameters. The serial correlations of all exogenous shocks are given beta prior distributions with mean 0.5 and standard deviation 0.2, except for those of the growth rates of the non-stationary shocks, g_t and g_t^m, which are given prior means of 0.3. The standard deviations of all shocks are given gamma distributions with mean and standard deviation 0.01 (or 1 percent), except for those of the monetary shocks z_t^m and g_t^m, which are given means and standard deviations of 0.0025 (or 1 percent per year).

Consider now the prior distributions of the parameters of the Taylor rule. The coefficients associated with inflation, the output-gap, and interest-rate smoothing are assigned standard values. Specifically, the inflation coefficient, α_π, has a gamma distribution with mean 1.5 and standard deviation 0.25. The output-gap coefficient, α_y, has a gamma distribution with mean 0.125 and standard deviation 0.1. And the interest-rate smoothing parameter, γ_I, has a uniform distribution with support [0 1]. The parameter governing the central bank information channel, α_ξ, has the same prior distribution as the output-gap coefficient, namely, a gamma distribution with mean 0.125 and standard deviation 0.1. This is motivated by the fact that, like α_y, the coefficient α_ξ represents the central bank's response to a measure of aggregate activity. Finally, the coefficient governing price stickiness, ϕ, has a gamma prior distribution with mean 50 and standard deviation 20, and the parameters governing habit formation, δ, and price indexation, γ_π, have uniform prior distributions with support [0 1].

Posterior moments are displayed in the last four columns of Table 2. As is common in estimated macroeconomic models, a number of parameters are imprecisely estimated. However, the estimation provides informative posteriors for the novel feature of the model, namely, the joint presence of a central bank information channel and a neo-Fisher effect. In particular, the estimation provides informative posteriors for the parameter governing the central bank's response to the preference shock, α_ξ, the parameters defining the law of motion of this shock, ρ_{ξ^c} and σ_{ξ^c}, and the standard deviation of the permanent monetary shock, σ_{g^m}. It is worth noting that even though the parameters governing the laws of motion of the two preference shocks, ξ_t^h and ξ_t^c, have identical priors, they have quite different posteriors. In particular, the preference shock to which the central bank responds, ξ_t^c, is significantly more volatile and persistent. From an economic point of view, this means that the central bank chooses to stabilize the most relevant component of the demand disturbance ξ_t. The estimation also yields precise estimates for the parameters defining nominal and real frictions, particularly the price stickiness parameter, ϕ, and the habit formation parameter, δ, which govern the endogenous propagation of exogenous shocks.

Interestingly, it is evident from Table 2 that the posterior estimates are fairly similar whether the estimation is conducted under full or imperfect information. Thus, in the analysis that follows, differences in the model's predictions under these two information structures can largely be attributed to the impact of informational frictions on the behavior of private agents.

Table 2: Prior and Posterior Parameter Distributions

	Prior Distribution			Posterior Distribution			
				Full Information		Imperfect Information	
Parameter	Distribution	Mean	Std	Mean	Std	Mean	Std
ϕ	Gamma	50	20	96.1	25.9	96.7	26.1
α_π	Gamma	1.5	0.25	1.55	0.226	1.55	0.232
α_y	Gamma	0.125	0.1	0.0863	0.0629	0.0889	0.0681
α_ξ	Gamma	0.125	0.1	0.0657	0.0199	0.0736	0.0253
ρ_{ξ^h}	Beta	0.5	0.2	0.567	0.197	0.601	0.188
ρ_{ξ^c}	Beta	0.5	0.2	0.916	0.0289	0.907	0.0423
ρ_{z^m}	Beta	0.5	0.2	0.484	0.212	0.54	0.212
ρ_{g^m}	Beta	0.3	0.2	0.238	0.163	0.265	0.18
σ_{ξ^h}	Gamma	0.01	0.01	0.0101	0.00433	0.0111	0.00547
σ_{ξ^c}	Gamma	0.01	0.01	0.0248	0.00577	0.0234	0.00594
σ_{z^m}	Gamma	0.0025	0.0025	0.00061	0.000384	0.000631	0.000387
σ_{g^m}	Gamma	0.0025	0.0025	0.000889	0.000426	0.000842	0.000422
γ_π	Uniform	0.5	0.289	0.296	0.16	0.339	0.17
γ_I	Uniform	0.5	0.289	0.217	0.111	0.18	0.0834
δ	Uniform	0.5	0.289	0.353	0.081	0.333	0.0794
ρ_z	Beta	0.5	0.2	0.482	0.196	0.484	0.193
ρ_g	Beta	0.3	0.2	0.195	0.0968	0.19	0.0944
σ_z	Gamma	0.01	0.01	0.00162	0.00128	0.00159	0.00129
σ_g	Gamma	0.01	0.01	0.00791	0.00104	0.00795	0.00106
R_{11}	Uniform	3.16e-06	1.82e-06	3.92e-06	1.72e-06	3.95e-06	1.74e-06
R_{22}	Uniform	2.1e-06	1.21e-06	3.71e-06	3.06e-07	3.72e-06	3.02e-07
R_{33}	Uniform	2.49e-07	1.44e-07	2.32e-07	1.4e-07	2.34e-07	1.41e-07
χ				0.98	0.133	0.95	0.124

Notes. The time unit is one quarter. The posterior distribution of χ is derived from the corresponding distribution of δ. The parameters R_{ii}, for $i = 1, 2$, and 3, are the diagonal elements of the variance-covariance matrix of measurement errors.

4 Results

Using the estimated model, this section characterizes the macroeconomic consequences of permanent monetary shocks and the central bank information channel. It begins with the full information environment and then turns to the one with imperfect information.

4.1 Full Information

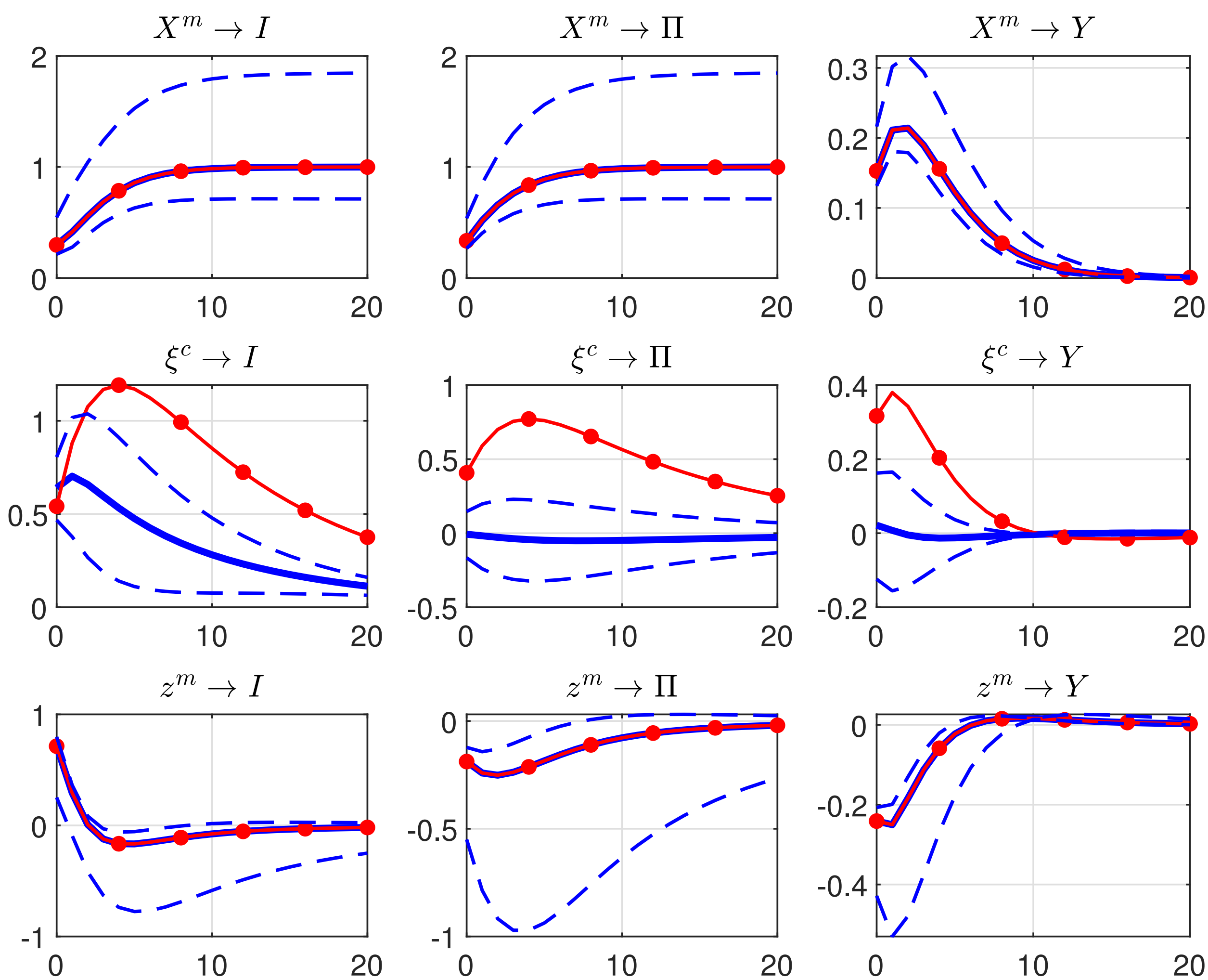
Under full information, households and firms can observe separately all shocks buffeting the economy, that is, the two demand shocks, ξ_t^h and ξ_t^c, the stationary and nonstationary monetary shocks, z_t^m and X_t^m, and the stationary and nonstationary productivity shocks, z_t and g_t.

Figure 1 displays impulse response functions to X_t^m, ξ_t^c, and z_t^m under full information. The permanent monetary shock produces a significant neo-Fisher effect: In response to an innovation in X_t^m that increases the nominal interest rate and inflation by 1 annual percentage point in the long run, the interest rate, inflation, and output all increase in the short run. Just two quarters after the shock, inflation is already halfway to its higher long-run value. Output rises by 15 basis points on impact, reaches a peak of 20 basis points two quarters after the shock and then converges to its pre-shock level gradually over time.

The intuition behind this result is as follows. When the innovation in X_t^m is revealed, firms know that inflation will be higher in the long run, as an increase in X_t^m is akin to an increase in the central bank's de facto inflation target.[2] Because firms face price adjustment costs, it pays for them to front load price increases in anticipation. Inflation actually adjusts faster than the interest rate in the short run, which causes a fall in the real interest rate and consequently an expansion in aggregate activity.

[2]It is important to distinguish between the de jure inflation target, which in the United States has been constant at 2 percent since the Bernanke era, from the de facto inflation target, which has to do with actual monetary policy and its implications for the permanent component of interest rates. For example, long spells of high nominal interest rates and inflation (as in the 1960s and 1970s) are associated with de facto high inflation targets (high estimated values of X_t^m) and vice versa (e.g., the period 2008 to 2021).

Figure 1: Estimated Impulse Responses Under Full Information



Notes. The horizontal axes measure quarters after the shock. Solid lines are posterior means, dashed lines are 95% asymmetric error bands computed using the Sims-Zha (1999) method, and circled lines are posterior means restricting $\alpha_\xi = 0$ without reestimation. Inflation, Π_t, and the nominal interest rate, I_t, are deviations from pre-shock levels and are expressed in percentage points per year. Output, Y_t, is measured in percent deviations from trend. The size of the permanent monetary shock X_t^m is set so as to increase the nominal interest rate by 1 annual percentage point in the long run on average. The size of the transitory monetary shock z_t^m is 1 annual percentage point on impact. And the size of the demand shock ξ_t^c is one standard deviation.

The estimated model also predicts a significant central bank information channel of monetary policy, as the central bank actively stabilizes demand shocks: Figure 1 shows that in response to a one-standard-deviation innovation in ξ_t^c, the policy rate increases by 64 basis points and reaches a peak of 70 basis points one quarter after the shock. Neither inflation nor output respond significantly to the preference shock. But this is a reflection of the CBI channel at work, that is, of the central bank successfully stabilizing the economy by directly responding to this type of disturbance ($\alpha_\xi > 0$).

To see this, Figure 1 also displays with circled lines the economy's response to a ξ_t^c shock under the counterfactual that the central bank does not respond directly to this type of disturbance, that is, when α_ξ is set to zero. In this case, the preference shock causes a large increase in inflation and output. Perhaps surprisingly, the interest rate also displays a much larger increase. That is, when the central bank information channel is active ($\alpha_\xi > 0$) the central bank can achieve a more stable path for inflation and output with a smaller increase in the nominal rate than when the CBI channel is shut down ($\alpha_\xi = 0$).

The reason for this has to do with the shape of the path of the interest rate. In the presence of the CBI channel, the nominal rate is highest in the beginning and falls gradually over time mimicking the path of the AR(1) preference shock. In other words, monetary conditions are tighter precisely when the desire to consume is stronger, which is conducive to macroeconomic stability. By contrast, when the CBI channel is shut down, the response of the interest rate is hump shaped, which implies that the interest rate is relatively low when the desire to consume is highest and that the interest rate increases as the desire to consume weakens. This shape of the impulse response of the interest rate therefore destabilizes the macroeconomy.

The third row of Figure 1 shows that a monetary tightening stemming from an increase in the transitory monetary shock z_t^m produces conventional effects, namely, a fall in inflation and output.

Table 3 displays the variance decomposition of the variables of interest. According to

Table 3: Variance Decomposition Under Full Information

Shock	α_ξ Estimated			$\alpha_\xi = 0$		
	ΔI_t	$\Delta \Pi_t$	ΔY_t	ΔI_t	$\Delta \Pi_t$	ΔY_t
Permanent Monetary Shock, g_t^m	6	33	2	6	15	1
Preference Shock, ξ_t^c	53	7	2	56	57	18
Transitory Interest-Rate Shock, z_t^m	9	4	1	8	2	1
Preference Shock, ξ_t^h	25	44	26	24	21	22
Transitory Productivity Shock, z_t	5	8	2	4	3	1
Permanent Productivity Shock, g_t	3	4	68	2	2	57

Notes. Posterior means. Shares are expressed in percent. The variables ΔI_t, $\Delta \Pi_t$, and ΔY_t denote the change in the nominal interest rate, the change in the inflation rate, and the output growth rate. The last three columns display the variance decomposition under the counterfactual $\alpha_\xi = 0$ without reestimation.

the estimated model, both the neo-Fisher effect and the central bank information effect are relevant drivers of the data. The permanent monetary shock, X_t^m, is important in explaining inflation, accounting for one third of the variance of changes in Π_t. To assess the importance of the CBI channel, we compare the contribution of the preference shock ξ_t^c to the variance of changes in inflation and output when the policy coefficient α_ξ takes its estimated value with the contribution when it is set to zero. When we shut down the CBI channel, the contribution of ξ_t^c to explaining the variance of changes in inflation and output increases by 50 and 15 percentage points, respectively. The CBI channel also affects the overall volatility of macroeconomic indicators. In the counterfactual exercise in which the CBI channel is shut down, the variance of inflation more than doubles and that of output changes increases by more than 20 percent. These results suggest that the CBI channel is important. Put differently, the fact that the central bank has information about a preference shock and responds directly to it significantly stabilizes the economy.

Finally, Table 3 shows that once one allows for neo-Fisher and central bank information effects, the standard monetary shock z_t^m plays a negligible role in explaining movements in output or inflation.

4.2 Imperfect Information

We have established that there is a significant central bank information effect. Is there, in addition, a central bank information advantage effect? To address this question, in this section we present results from the estimation of the economy with imperfect information.

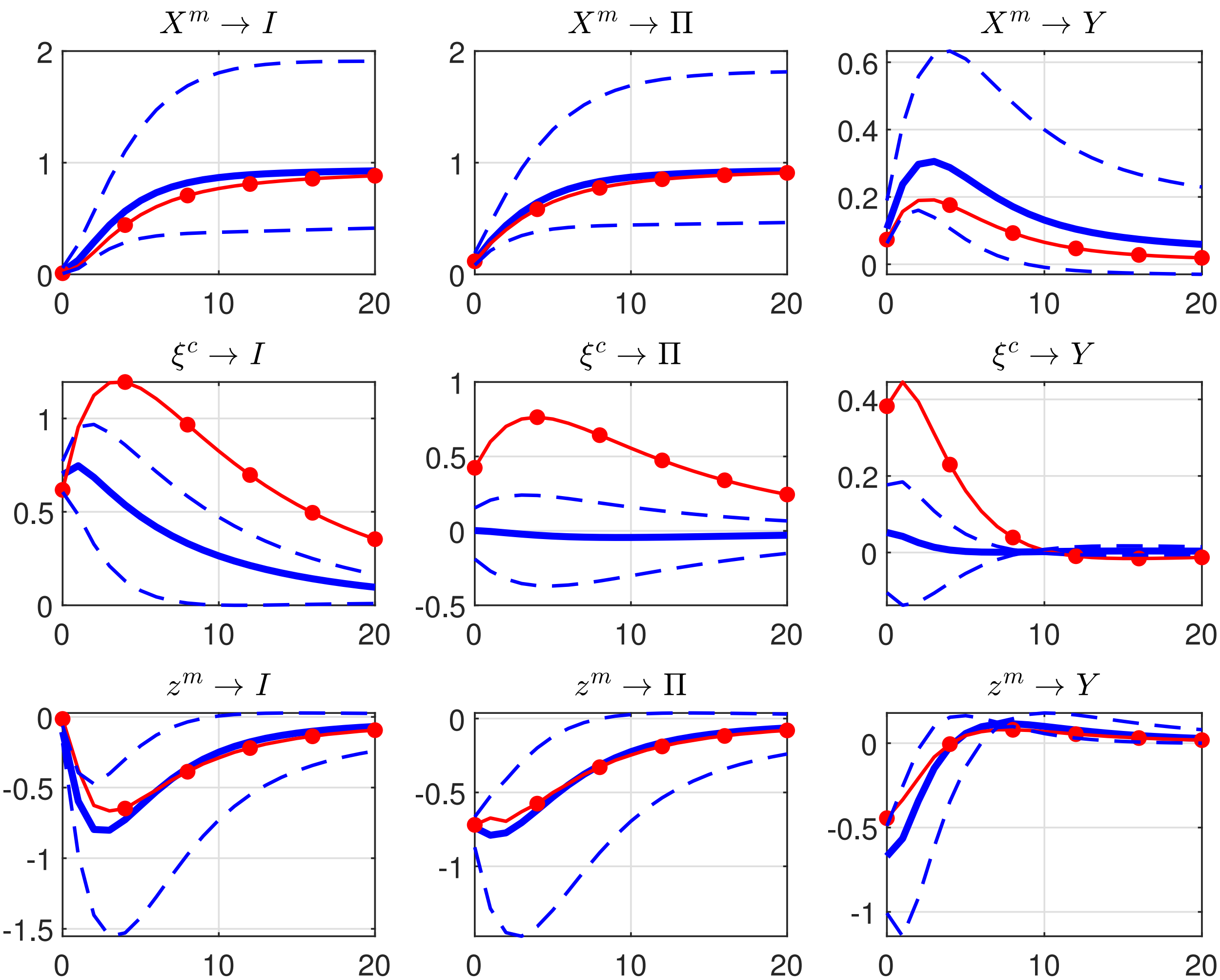
Recall that under imperfect information, private agents observe the stochastic component of the Taylor rule, $\widetilde{\Omega}_t^m \equiv X_t^{m\,1-\alpha_\pi(1-\gamma_I)} X_{t-1}^{m\;\;-\gamma_I} e^{z_t^m+\alpha_\xi \xi_t^c}$, but not the individual shocks that drive it, namely, the two monetary shocks, X_t^m and z_t^m, and the demand shock ξ_t^c. Also, under imperfect information private agents observe the preference shifter ξ_t, but not separately its two components ξ_t^h and ξ_t^c. As it turns out, however, the equilibrium dynamics are not too different under imperfect information than under perfect information. We interpret this result as suggesting that the central bank does not possess a significant information advantage vis-à-vis the private sector, at least at quarterly frequency.

Figure 2 displays impulse responses to X_t^m, ξ_t^c, and z_t^m under imperfect information. An increase in the permanent monetary shock continues to produce a significant neo-Fisher effect, as the interest rate, inflation, and output all increase in the short run in response to an increase in X_t^m. Quantitatively, the reaction of the nominal interest rate on impact is somewhat more muted relative to the full information case, but overall the economy continues to reach its long-run position relatively quickly and the expansionary effect on output is little changed.

A positive innovation in the demand shock ξ_t^c continues to produce a significant and persistent tightening, and the monetary authority achieves a virtually perfect stabilization of inflation and output. Quantitatively, the responses of I_t, Π_t, and Y_t are almost identical to those implied by the full information economy. When we counterfactually shut down the central bank's reaction to ξ_t^c by setting α_ξ to zero, both inflation and output display large and significant increases, just as under full information.

One difference with the full information case is the response to a stationary monetary shock z_t^m, especially the response of the nominal interest rate. Under imperfect information,

Figure 2: Estimated Impulse Responses Under Imperfect Information



Notes. The horizontal axes measure quarters after the shock. Solid lines are posterior means, dashed lines are 95% asymmetric error bands computed using the Sims-Zha (1999) method, and circled lines are posterior means restricting $\alpha_\xi = 0$ without reestimation. Inflation, Π_t, and the nominal interest rate, I_t, are deviations from pre-shock levels and are expressed in percentage points per year. Output, Y_t, is measured in percent deviations from trend. The size of the permanent monetary shock X_t^m is set so as to increase the nominal interest rate by 1 annual percentage point in the long run on average. The size of the transitory monetary shock z_t^m is 1 annual percentage point on impact. And the size of the demand shock ξ_t^c is one standard deviation.

when z_t^m goes up, private agents know that the increase in the exogenous component of the Taylor rule is most likely not due to a demand shock, since they know that ξ_t did not move (and that a move in one of its components, ξ_t^h or ξ_t^c, perfectly offset by the other is highly unlikely). So they are quite sure that they are in the presence of a monetary shock. But they are not sure whether the monetary innovation is a stationary or a permanent one (z_t^m or X_t^m). Since the exogenous component of the Taylor rule, $\widetilde{\Omega}_t^m \equiv X_t^{m\,1-\alpha_\pi(1-\gamma_I)} X_{t-1}^{m\;\;-\gamma_I} e^{z_t^m+\alpha_\xi \xi_t^c}$, is increasing in z_t^m but decreasing in X_t^m, agents think that the economy could have been hit either with an increase in z_t^m or with a decrease in X_t^m. Both of these possibilities tend to produce falls in inflation and output. So the transition in response to an increase in z_t^m is characterized by paths of Π_t and Y_t below trend. The response of the interest rate is ambiguous, because an increase in z_t^m induces an increase in I_t, whereas a fall in output and inflation induces a decrease.

Table 4 displays the variance decomposition under imperfect information. Movements in X_t^m explain 20 percent of the variance of inflation changes, suggesting that the permanent monetary shock continues to be an important driver of inflation, though less so than under full information. The central bank information channel is somewhat stronger under imperfect information. When we counterfactually shut down the central bank's response to the preference shock ξ_t^c by setting α_ξ equal to zero, the share of the variances of inflation changes and output growth explained by this shock increase by 56 and 24 percentage points, respectively, compared to 50 and 15 percentage points under full information.

The reason why the full and imperfect information cases deliver similar equilibrium dynamics is that the three shocks that are imperfectly observed, namely, the permanent monetary shock, the preference shock to which the central bank responds, and the transitory monetary shock, produce starkly different dynamics after the period of impact, allowing private agents to learn quickly about the nature of the disturbances buffeting the economy.

We also consider an intermediate case between the full information and the imperfect information specifications in which private agents can observe ξ_t and $\widetilde{\Omega}_t^m$, as in the imperfect

Table 4: Variance Decomposition Under Imperfect information

	α_ξ Estimated			$\alpha_\xi = 0$		
Shock	ΔI_t	$\Delta \Pi_t$	ΔY_t	ΔI_t	$\Delta \Pi_t$	ΔY_t
Permanent Monetary Shock, g_t^m	4	20	2	4	10	1
Preference Shock, ξ_t^c	61	7	2	68	63	26
Transitory Interest-Rate Shock, z_t^m	5	24	7	5	8	2
Preference Shock, ξ_t^h	23	39	16	16	15	8
Transitory Productivity Shock, z_t	5	7	2	5	3	1
Permanent Productivity Shock, g_t	2	3	72	2	1	62

Notes. Posterior means, in percent. The variables ΔI_t, $\Delta \Pi_t$, and ΔY_t denote the change in the nominal interest rate, the change in the inflation rate, and the output growth rate.

information case, and also noisy signals of the individual shocks g_t^m, ξ_t^c, and z_t^m. The result of this robustness analysis, which in the interest of space we do not present, is that the noise components are imprecisely estimated and the predictions of the model are not significantly different from those of the imperfect information specification. This should not come as a surprise, given that the full and imperfect information cases were found to deliver similar results and the noisy-information case is an intermediate one.

The overall takeaway of this and the preceding subsection is that in quarterly data the neo-Fisher and central bank information effects are significant, while there is relatively little support for a central bank information advantage. From a practical standpoint, in negotiating the tradeoff between complexity of the model and economic insight, the full information benchmark appears as a reasonable framework to interpret the data. Accordingly, the analysis that follows is conducted using the full information specification.

4.3 High-Frequency Information

We now estimate the model with an additional observation equation that incorporates a measure of monetary policy shocks derived from high-frequency information. In the context of the present model, high-frequency monetary shocks capture unforecastable changes in the exogenous stochastic component of the Taylor rule, namely, $\ln \widetilde{\Omega}_t^m - E_{t-1} \ln \widetilde{\Omega}_t^m$, where $\widetilde{\Omega}_t^m$ is defined in equation (19). This is because within the short time span used to estimate surprise changes in interest rates, typically a 30-minute window around FOMC announcements, one can safely assume that inflation and output—the two macroeconomic indicators entering the Taylor rule—are unchanged.

Letting hf_t be the high-frequency monetary shock, we assume that it is linked to the forecast error of the exogenous component of the Taylor rule by the expression

$$hf_t = \alpha_{hf}(\ln \widetilde{\Omega}_t^m - E_{t-1} \ln \widetilde{\Omega}_t^m) + \mu_t^{hf},$$

where α_{hf} is a scaling parameter and μ_t^{hf} is an exogenous i.i.d. disturbance with mean zero and standard deviation $\sigma_{\mu^{hf}}$, capturing measurement error. From the definition of $\widetilde{\Omega}_t^m$, we can write hf_t in terms of the innovations of the individual shocks entering the interest-rate feedback rule. This gives

$$hf_t = \alpha_{hf} \left[\sigma_{zm} \epsilon_t^{zm} + \alpha_\xi \sigma_{\xi^c} \epsilon_t^{\xi^c} + (1 - \alpha_\pi(1-\gamma_I)) \sigma_{g^m} \epsilon_t^{g^m} \right] + \mu_t^{hf}, \tag{34}$$

where the disturbances ϵ_t^x, for $x = z^m, \xi^c$, and g^m are defined in equation (20). The high-frequency shock is driven by innovations in the traditional monetary shock, $\epsilon_t^{z^m}$, the preference shock to which the central bank responds, $\epsilon_t^{\xi^c}$, and the permanent monetary shock, $\epsilon_t^{g^m}$.

We estimate the full-information model of section 4.1 incorporating equation (34) as an observation equation. We measure hf_t using the time series NS provided by Acosta (2023), which he constructs following the methodology employed by Nakamura and Steinsson (2018). For each quarter, hf_t is the sum of the high-frequency monetary shocks NS occurring at the FOMC announcements taking place in that particular quarter. The NS shock is an index with mean 0 and unit standard deviation. Without loss of generality, we normalize its standard deviation to 0.0025, or 1 percent per year. The time series of hf_t starts in 1995:Q1, whereas the time series of the other observables used in the estimation of the model (changes in the policy rate, the interest-rate-inflation differential, and the output growth rate) start in 1961:Q3. We therefore treat values of hf_t prior to 1995:Q1 as missing observations (Harvey, 1989).

The present formulation features two additional parameters vis-à-vis the baseline model of section 4.1: α_{hf} and $\sigma^2_{\mu^{hf}}$. We re-estimate all parameters of the model using Bayesian methods. We assume that $\sigma^2_{\mu^{hf}}$ has a gamma prior distribution with mean and standard deviation equal to 10 percent of the observed variance of hf_t. To form the prior distribution of α_{hf}, we start by calculating a reference value for it. Specifically, by equation (34), we have that $\text{var}(hf_t) = \alpha^2_{hf}\text{var}(\ln\widetilde{\Omega}^m_t - E_{t-1}\ln\widetilde{\Omega}^m_t) + \sigma^2_{\mu^{hf}}$. The posterior mean of $\text{std}(\ln\widetilde{\Omega}^m_t - E_{t-1}\ln\widetilde{\Omega}^m_t)$ in the full-information estimation of section 4.1 is 0.0017, or 0.68 percent per year. Evaluating the above expression at this value, setting the variance of hf_t at its normalized value, and the variance of μ^{hf}_t at its prior mean, gives $0.0025^2 = \alpha^2_{hf} \times 0.0017^2 + 0.1 \times 0.0025^2$, which implies a reference value for α_{hf} of 1.4. We assume a uniform prior distribution for α_{hf} with lower bound 0 and upper bound 4. This upper bound is about 3 times the reference value of α_{hf}. The prior distributions of all other estimated parameters are as shown in Table 2.

Table B1 in Appendix B displays prior and posterior parameter distributions. The posterior mean of α_{hf} is 2.1, which is similar to its prior mean of 2. However, its posterior standard deviation is 0.54, which is about half as large as its prior counterpart of 1.1, suggesting that the scaling parameter is identified. The posterior variance of the measurement error μ^{hf}_t is 34 percent of the variance of the observable hf_t (more than three times as large as its prior value), indicating that according to the model the time series hf_t contains substantial measurement error.

The parameters that are common to the baseline model of section 4.1 overall have similar posterior distributions, with two exceptions. One is the parameters defining the law of motion of the permanent monetary shock, σ_{g^m} and ρ_{g^m}, which now imply a standard deviation of g^m_t that is 73 percent larger than its counterpart in the model estimated without high-frequency

Table 5: Estimation with High Frequency Shocks: Variance Decomposition

	α_ξ Estimated			$\alpha_\xi = 0$		
Shock	ΔI_t	$\Delta \Pi_t$	ΔY_t	ΔI_t	$\Delta \Pi_t$	ΔY_t
Permanent Monetary Shock, g_t^m	21	72	4	15	22	2
Preference Shock, ξ_t^c	62	11	5	71	74	38
Transitory Interest-Rate Shock, z_t^m	11	2	2	9	1	1
Preference Shock, ξ_t^h	3	6	6	2	2	4
Transitory Productivity Shock, z_t	3	6	1	2	2	1
Permanent Productivity Shock, g_t	1	2	82	1	1	54

Notes. Posterior means, in percent. The variables ΔI_t, $\Delta \Pi_t$, and ΔY_t denote the change in the nominal interest rate, the change in the inflation rate, and the output growth rate.

shocks. The other are the parameters defining the stochastic process of the preference shock ξ_t^c and the coefficient governing the monetary authority's response to this shock. Specifically, ξ_t^c is now 35 percent more volatile and the policy parameter α_ξ falls by about 40 percent.

Table 5 displays the predicted variance decomposition of changes in the policy rate, inflation, and output. The permanent monetary shock, g_t^m, now accounts for over 70 percent of the variance in inflation changes, more than twice its contribution in the baseline estimation without high-frequency information. This increase comes largely at the expense of the preference shock to which the central bank does not respond, ξ_t^h, whose share falls sharply from 44 percent to 6 percent.

The central bank information effect also becomes more prominent relative to the baseline. When we counterfactually shut down this effect by setting α_ξ equal to zero, the share of the variance of inflation changes explained by the preference shock ξ_t^c rises by 63 percentage points, and its contribution to the variance of output growth increases by 33 percentage points. These figures compare to 50 and 15 percentage points, respectively, in the baseline estimation.

Figure B1 in Appendix B displays the impulse responses to the permanent monetary shock, the preference shock to which the central bank responds, and the transitory monetary shock. The results are in line with those obtained when the estimation does not include high-frequency shocks except that now output is somewhat more responsive to tightenings originated in ξ_t^c shocks, which is consistent with the smaller estimated value of α_ξ.

Overall, the findings of this section suggest that including information on high-frequency monetary shocks in the estimation of the model increases the importance of the neo-Fisher and central bank information effects.

4.4 Longer Maturity Yields

Incorporating information about long-maturity bonds in the model estimation can improve the identification of structural shocks, because different shocks can imply distinct predictions for long-term yields. For instance, Figure 1 illustrates that the short rate converges to its long-run level from below in response to an increase in the permanent monetary shock, X_t^m, but from above in response to an increase in the preference shock to which the central bank reacts, ξ_t^c. Since long rates are approximately moving averages of short rates, one would expect long rates to rise more than short rates in the short run following a positive innovation in X_t^m, but less following a positive innovation in ξ_t^c. Therefore, including both short- and long-maturity yields in the estimation should improve the identification of the neo-Fisher and central bank information effects.

Accordingly, we now assume that households can hold bonds of different maturities. With this asset structure, the household budget constraint can be expressed as

$$P_t C_t + \sum_{h=1}^{H} Q_{ht} B_{ht} + T_t = \sum_{h=1}^{H} Q_{h-1t} B_{ht-1} + W_t h_t + \Phi_t,$$

where the variable B_{ht} denotes a zero-coupon bond trading at price Q_{ht} in period t and paying 1 dollar in period $t+h$, with $Q_{0t} \equiv 1$. The zero-coupon nominal yield on an h-period bond, denoted I_t^h, is defined as

$$1 + I_t^h = Q_{ht}^{-\frac{1}{h}},$$

with $I_t \equiv I_t^1$. The first-order conditions of the household's optimization problem with respect to bond holdings are

$$\Lambda_t Q_{ht} = \beta E_t \left[\frac{\Lambda_{t+1}}{1+\Pi_{t+1}} Q_{h-1t+1} \right],$$

for $h = 1, 2, \ldots, H$. All other aspects of the model are as in the baseline formulation of section 2.

In the estimation of the model we include as an observable the change in the 12-quarter zero-coupon yield, ΔI_t^{12}, in addition to changes in the short-run nominal rate, the short-run interest rate-inflation differential, and changes in output. For I_t^{12} we use the estimate of the 3-year zero coupon Treasury yield produced by Gürkaynak, Sack, and Wright (2006).[3] To preserve comparability with the baseline results of section 4.1, the estimation does not include the high-frequency monetary shock as an observable. The results presented below are robust to including this variable as a fifth observable.

Table C1 in Appendix C displays posterior moments of the estimated parameters. As conjectured, the inclusion of information on longer maturity yields produces parameter estimates with smaller posterior standard deviations, indicating that the new observable is informative. The parameter estimates are in general stable relative to the baseline estimation with three observables (Table 2).

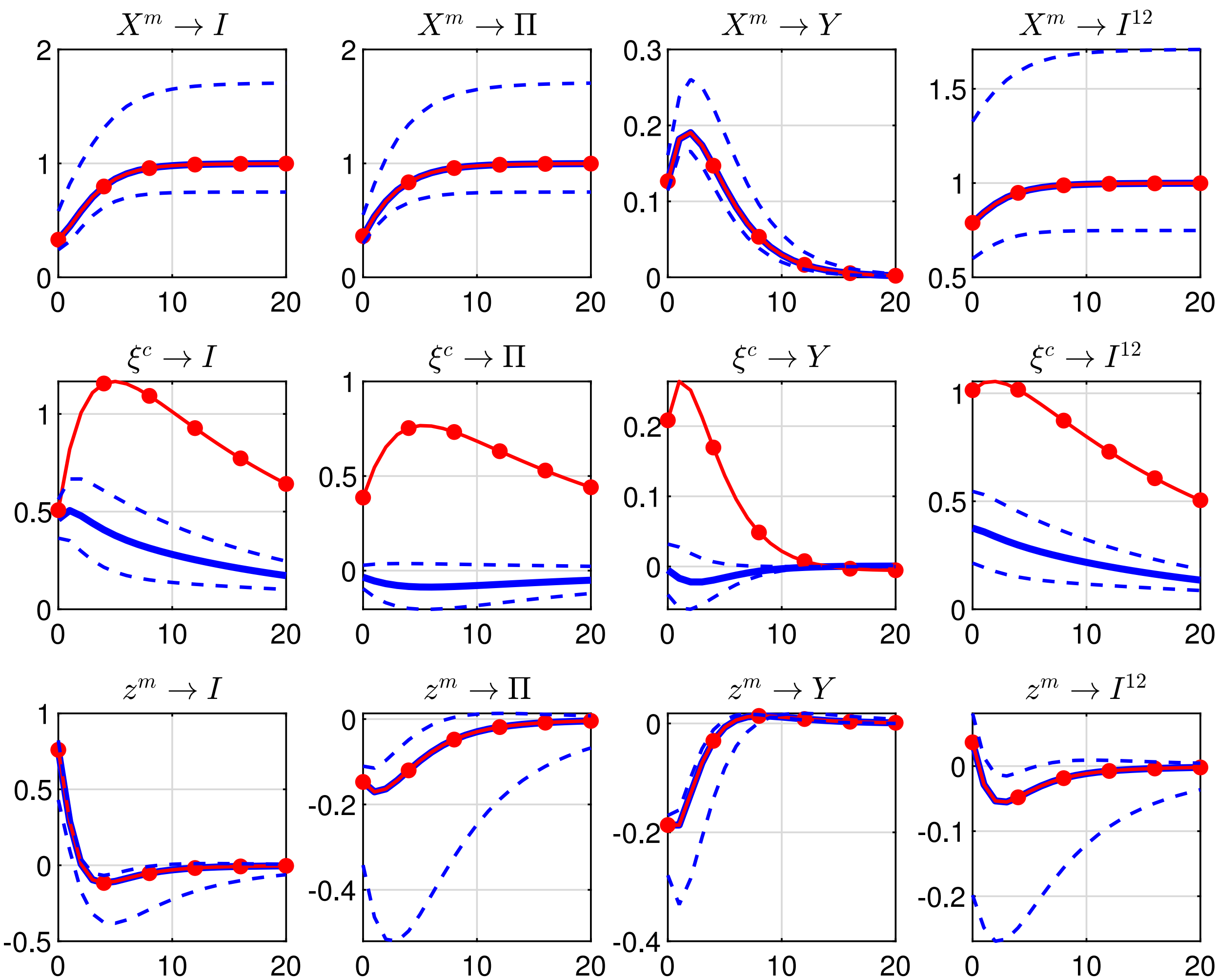
Figure 3 displays posterior impulse responses when the model is estimated with the 12-quarter zero-coupon yield as an additional observable. The predicted dynamics are in general similar to the baseline case. The error bands are now narrower, confirming that the inclusion of the long-term yield helps to identify the parameters of the model. The permanent monetary shock continues to produce, in response to an unexpected tightening, a significant increase in inflation and output in the short run. As before, the preference shock to which the central bank responds does not have a significant effect on these two variables. But under the counterfactual $\alpha_\xi = 0$, an unexpected increase in the preference shock ξ_t^c

[3]Specifically, we use their series SVNY03, which is publicly available at the Board of Governors of the Federal Reserve System's website, `www.federalreserve.gov/data/nominal-yield-curve.htm`. The raw data is daily and we transform it to a quarterly frequency by simple averaging. It is available for our sample period, 1961Q3 to 2019Q4.

continues to cause sizable increases in inflation and output in the short run, suggesting a significant central bank information effect. The response of the twelve-quarter yield is a forward moving average of that of the short-run interest rate, and as a result it inherits much of its qualitative characteristics.

Table C2 in Appendix C displays the variance decomposition of endogenous variables of interest. The neo-Fisher shock X_t^m continues to be the second most important driver of inflation changes, after the demand shock to which the central bank does not respond, ξ_t^h. It explains 19 percent of the variance of $\Delta\Pi_t$, which is a sizeable fraction, but smaller than the one obtained in the baseline estimation (33 percent). The central bank information effect continues to play an important role in explaining the variance of macroeconomic variables. When we shut it down by setting the policy coefficient α_ξ to zero, the contribution of the preference shock ξ_t^c to the variance of changes in inflation and output growth increases by 50 and 8 percentage points, respectively, compared to 50 and 15 percentage points in the baseline estimation. The transitory monetary shock z_t^m now explains a larger fraction of changes in the short term interest rate, 25 percent versus 9 percent in the estimation with three observables. This is due to a significantly higher estimated standard deviation of the innovation to z_t^m. However, z_t^m explains a small fraction of movements in the 12-quarter zero-coupon rate and continues to play a negligible role in explaining movements in inflation and output. The preference shock to which the central bank does not respond, ξ_t^h, becomes more important, now explaining 58 percent of the variance of inflation changes and 41 percent of that of output changes.

Figure 3: Estimation with the Twelve-Quarter Yield: Impulse Responses



Notes. The horizontal axes measure quarters after the shock. Solid lines are posterior means, dashed lines are 95% asymmetric error bands computed using the Sims-Zha (1999) method, and circled lines are posterior means restricting $\alpha_\xi = 0$ without reestimation. Inflation, Π_t, the nominal interest rate, I_t, and the twelve-quarter yield, I_t^{12}, are deviations from pre-shock levels and are expressed in percentage points per year. Output, Y_t, is measured in percent deviations from trend. The size of the permanent monetary shock X_t^m is set so as to increase the nominal interest rate by 1 annual percentage point in the long run on average. The size of the transitory monetary shock z_t^m is 1 annual percentage point on impact. And the size of the demand shock ξ_t^c is one standard deviation.

5 Summary and Conclusion

The neo-Fisher effect and the central bank information effect produce similar macroeconomic outcomes: in both cases, a monetary tightening does not lead to a decline in inflation or real activity. This similarity raises the risk that separate empirical estimates of the two effects may conflate them. In this paper, we present the first attempt to jointly estimate both effects. We do so by incorporating into a dynamic general equilibrium model with nominal and real rigidities an interest-rate feedback rule that responds not only to output, inflation, and a transitory monetary shock, but also to a permanent monetary shock—capturing the neo-Fisher channel—and to a preference shock—capturing the central bank information channel. We estimate the model using quarterly postwar U.S. data, including information on high-frequency monetary shocks and long-term yields.

The estimated model suggests that both the neo-Fisher effect and the central bank information effect are important at business-cycle frequency: Permanent monetary shocks explain a significant fraction of movements in inflation, and the central bank's direct response to exogenous movements in aggregate demand goes a long way toward stabilizing inflation and output.

The paper clarifies the distinction between a central bank information effect and a central bank information advantage. The CBI effect arises from the central bank's direct and systematic response to observable real shocks. The CBI advantage, by contrast, presumes an informational asymmetry whereby the central bank acts on signals not available to the private sector. Our findings support the existence of the former but not the latter: the data do not suggest that the central bank possesses persistent informational advantages at the quarterly frequency.

The estimated model predicts that through its direct response to aggregate shocks, the central bank brings the real allocation closer to the one that would arise under flexible prices. This finding suggests that the central bank information channel could be conducive to a more efficient outcome. A promising line of investigation is ascertaining precisely how much closer the direct response of central banks to aggregate disturbances—of which the current formulation of the CBI channel is just one example—can bring the economy to the efficiency frontier. We leave this task for future work.

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Appendix

A Model Solution Under Imperfect Information

Under imperfect information, agents must form conditional expectations about future values of endogenous and exogenous variables, based on the current position of the observable states of the economy and knowledge of the law of motion of the unobserved exogenous states ξ_t^h, ξ_t^c, z_t^m, and g_t^m. To solve this signal extraction problem, we proceed as follows. Let $\boldsymbol{y}_t = [h_t \;\; y_t \;\; w_t \;\; mc_t \;\; \lambda_t \;\; \pi_t \;\; a_t]'$ be the vector of controls, $\boldsymbol{v}_t = [\; z_t \;\; g_t \;\; c_{t-1} \;\; y_{t-1}^n \;\; \tilde{\pi}_t \;\; i_{t-1} \,]'$, the vector of endogenous states and observable exogenous states, and

$$\boldsymbol{o}_t = \begin{bmatrix} \xi_t \\ g_t^{\omega m} \end{bmatrix} \tag{A1}$$

the vector of observable exogenous states used to extract information about the current and future expected positions of the unobservable exogenous states ξ_t^h, ξ_t^c, z_t^m, and g_t^m.

Let the lengths of $\boldsymbol{y}_t$, $\boldsymbol{v}_t$, and $\boldsymbol{o}_t$ be n_y, n_v and n_o. Linearize the equilibrium conditions (23)-(33). The resulting linearized expressions together with the AR(1) processes for the observed exogenous states included in $\boldsymbol{v}_t$ (i.e., z_t and g_t) can be written in as

$$\mathcal{A}\, E_t \begin{bmatrix} \hat{\boldsymbol{y}}_{t+1} \\ \hat{\boldsymbol{v}}_{t+1} \\ \boldsymbol{o}_{t+1} \end{bmatrix} = \mathcal{B} \begin{bmatrix} \hat{\boldsymbol{y}}_t \\ \hat{\boldsymbol{v}}_t \\ \boldsymbol{o}_t \end{bmatrix}, \tag{A2}$$

where hatted variables refer to deviations from steady-state values. (The vector $\boldsymbol{o}_t$ is not hatted, as its steady-state value is zero, so it is already expressed in deviations from steady state.)

The system (A2) has $n_y + n_v$ equations and $n_y + n_v + n_o$ variables. Let $\boldsymbol{u}_t \equiv [\xi_t^h \;\; \xi_t^c \;\; \xi_{t-1}^c \;\; z_t^m \;\; z_{t-1}^m \;\; g_t^m \; g_{t-1}^m]'$ be the vector of unobserved exogenous states with length n_u. Then, from the law of motion of the exogenous driving forces given in (20) we have that

$$\boldsymbol{u}_{t+1} = F\boldsymbol{u}_t + B\boldsymbol{\epsilon}^u_{t+1} \tag{A3}$$

and from equations (2), (22), and (A1) we have that

$$\boldsymbol{o}_t = H'\boldsymbol{u}_t \tag{A4}$$

with

$$F = \begin{bmatrix} \rho_{\xi h} & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & \rho_{\xi c} & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & \rho_{zm} & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & \rho_{gm} & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 \end{bmatrix}, \quad B = \begin{bmatrix} \sigma_{\xi h} & 0 & 0 & 0 \\ 0 & \sigma_{\xi c} & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & \sigma_{zm} & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & \sigma_{gm} \\ 0 & 0 & 0 & 0 \end{bmatrix},$$

$$H' = \begin{bmatrix} 1 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & \frac{\alpha_\xi}{a} & -\frac{\alpha_\xi}{a} & \frac{1}{a} & -\frac{1}{a} & \frac{a+\gamma_I}{a} & \frac{-\gamma_I}{a} \end{bmatrix}, \quad \text{and} \quad \boldsymbol{\epsilon}^u_t = \begin{bmatrix} \epsilon^{\xi h}_t \\ \epsilon^{\xi c}_t \\ \epsilon^{zm}_t \\ \epsilon^{gm}_t \end{bmatrix},$$

where $a \equiv (1-\alpha_\pi)(1-\gamma_I)$. Let $\boldsymbol{\eta}_t \equiv E_{t-1}\boldsymbol{u}_t$ be the expected value of $\boldsymbol{u}_t$ conditional on $\boldsymbol{o}_{t-1}$. Then, applying the Kalman filter yields

$$\boldsymbol{\eta}_{t+1} = (F - KH')\boldsymbol{\eta}_t + K\boldsymbol{o}_t \tag{A5}$$

and

$$E_t\boldsymbol{o}_{t+1} = H'\boldsymbol{\eta}_{t+1}, \tag{A6}$$

where $K = FPH(H'PH)^{-1}$ is the Kalman gain, $P = F[P - PH(H'PH)^{-1}H'P]F' + Q$ is the steady-state mean square error of $\boldsymbol{\eta}_{t+1}$ expressed implicitly as a Ricatti equation, and $Q \equiv BB'$ is the variance-covariance matrix of the innovation $B\boldsymbol{\epsilon}_t^u$. Equation (A5) gives the law of motion of agents' expectation of the position of the latent exogenous state vector $\boldsymbol{u}_t$. This expectation changes over time as information about the observable state $\boldsymbol{o}_t$ arrives. Equation (A6) expresses the expected value of the observable state in period $t+1$, $E_t\boldsymbol{o}_{t+1}$, as a function of the expected position of the vector of unobservable states in $t+1$, $\boldsymbol{\eta}_{t+1}$.

The system consisting of (A2), (A5), and (A6) has $n_y + n_v + n_o + n_u$ equations and also $n_y + n_v + n_o + n_u$ unknowns. Solving this system taking $\hat{\boldsymbol{v}}_t$, $\boldsymbol{\eta}_t$, and $\boldsymbol{o}_t$ as states and $\hat{\boldsymbol{y}}_t$ as controls yields

$$\begin{bmatrix} \hat{\boldsymbol{v}}_{t+1} \\ \boldsymbol{\eta}_{t+1} \\ E_t\boldsymbol{o}_{t+1} \end{bmatrix} = h_x \begin{bmatrix} \hat{\boldsymbol{v}}_t \\ \boldsymbol{\eta}_t \\ \boldsymbol{o}_t \end{bmatrix} + \Sigma\boldsymbol{\epsilon}_{t+1} \tag{A7}$$

and

$$\hat{\boldsymbol{y}}_t = g_x \begin{bmatrix} \hat{\boldsymbol{v}}_t \\ \boldsymbol{\eta}_t \\ \boldsymbol{o}_t \end{bmatrix}, \tag{A8}$$

where, given values for the structural parameters of the model, h_x and g_x are known matrices, $\boldsymbol{\epsilon}_t = [\epsilon_t^z \ \epsilon_t^g]'$, and Σ contains the standard deviations of the elements of $\boldsymbol{\epsilon}_t$ in the corresponding positions.

Summarizing, the joint evolution of the state vectors $\hat{\boldsymbol{v}}_t$, $\boldsymbol{o}_t$, and $\boldsymbol{u}_t$ and the control vector $\hat{\boldsymbol{y}}_t$ is given by equations (A3), (A4), (A5), (A7), and (A8).

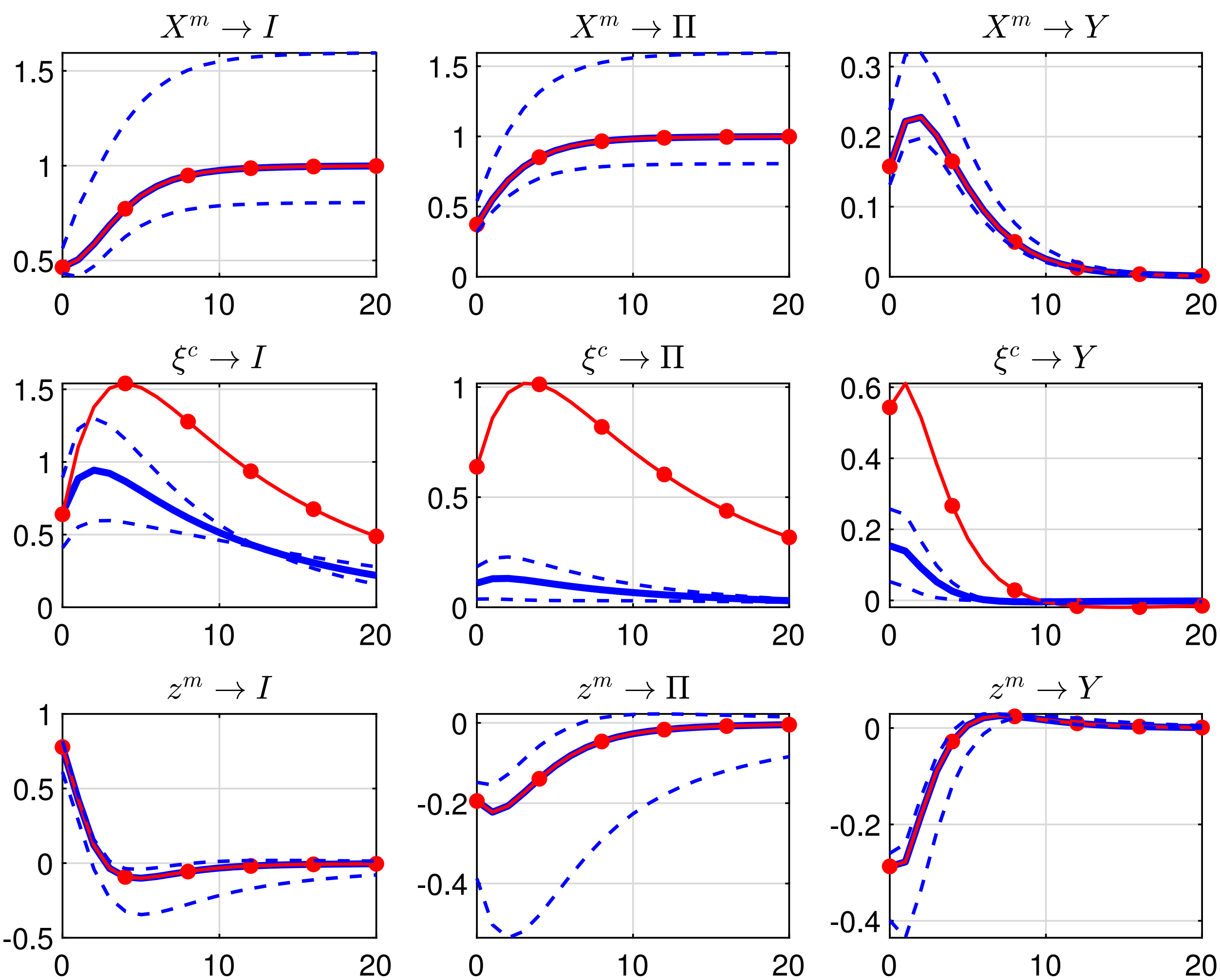
B High-Frequency Estimation: Additional Results

Table B1: Estimation with High Frequency Shocks: Prior and Posterior Parameter Distributions

	Prior Distribution			Posterior Distribution	
Parameter	Distribution	Mean	Std	Mean	Std
ϕ	Gamma	50	20	90	25.3
α_π	Gamma	1.5	0.25	1.53	0.204
α_y	Gamma	0.125	0.1	0.0979	0.0815
α_{hf}	Uniform	2	1.15	2.13	0.541
α_ξ	Gamma	0.125	0.1	0.0388	0.0106
ρ_{ξ^h}	Beta	0.5	0.2	0.499	0.21
ρ_{ξ^c}	Beta	0.5	0.2	0.916	0.0219
ρ_{z^m}	Beta	0.5	0.2	0.335	0.165
ρ_{g^m}	Beta	0.3	0.2	0.165	0.129
σ_{ξ^h}	Gamma	0.01	0.01	0.00322	0.00262
σ_{ξ^c}	Gamma	0.01	0.01	0.0334	0.00715
σ_{z^m}	Gamma	0.0025	0.0025	0.000714	0.00028
σ_{g^m}	Gamma	0.0025	0.0025	0.00156	0.000377
γ_π	Uniform	0.5	0.289	0.369	0.17
γ_I	Uniform	0.5	0.289	0.424	0.112
δ	Uniform	0.5	0.289	0.294	0.0617
ρ_z	Beta	0.5	0.2	0.487	0.201
ρ_g	Beta	0.3	0.2	0.175	0.0849
σ_z	Gamma	0.01	0.01	0.00152	0.00114
σ_g	Gamma	0.01	0.01	0.00822	0.000998
R_{11}	Uniform	3.16e-06	1.82e-06	3.73e-06	1.77e-06
R_{22}	Uniform	2.1e-06	1.21e-06	3.75e-06	2.95e-07
R_{33}	Uniform	2.49e-07	1.44e-07	2.49e-07	1.41e-07
$\sigma^2_{\mu^{hf}}$	Gamma	6.25e-07	6.25e-07	2.15e-06	1.29e-06
χ				0.891	0.0819

Notes. The time unit is one quarter. The posterior distribution of χ is derived from the corresponding distribution of δ. The parameters R_{ii}, for $i = 1, \ldots, 3$ are the diagonal elements of the variance-covariance matrix of measurement errors.

Figure B1: Estimation with High Frequency Shocks: Impulse Responses



Notes. The horizontal axes measure quarters after the shock. Solid lines are posterior means, dashed lines are 95% asymmetric error bands computed using the Sims-Zha (1999) method, and circled lines are posterior means restricting $\alpha_\xi = 0$ without reestimation. Inflation, Π_t, and the nominal interest rate, I_t, are deviations from pre-shock levels and are expressed in percentage points per year. Output, Y_t, is measured in percent deviations from trend. The size of the permanent monetary shock X_t^m is set so as to increase the nominal interest rate by 1 annual percentage point in the long run on average. The size of the transitory monetary shock z_t^m is 1 annual percentage point on impact. And the size of the demand shock ξ_t^c is one standard deviation.

C Longer-Maturity Yields: Additional Results

Table C1: Estimation with the Twelve-Quarter Yield: Prior and Posterior Parameter Distributions

	Prior Distribution			Posterior Distribution	
Parameter	Distribution	Mean	Std	Mean	Std
ϕ	Gamma	50	20	84	21.4
α_π	Gamma	1.5	0.25	1.53	0.207
α_y	Gamma	0.125	0.1	0.112	0.0591
α_ξ	Gamma	0.125	0.1	0.0396	0.0123
ρ_{ξ^h}	Beta	0.5	0.2	0.431	0.1
ρ_{ξ^c}	Beta	0.5	0.2	0.954	0.0121
ρ_{z^m}	Beta	0.5	0.2	0.384	0.177
ρ_{g^m}	Beta	0.3	0.2	0.216	0.15
σ_{ξ^h}	Gamma	0.01	0.01	0.0121	0.00221
σ_{ξ^c}	Gamma	0.01	0.01	0.0318	0.00783
σ_{z^m}	Gamma	0.0025	0.0025	0.00114	0.000262
σ_{g^m}	Gamma	0.0025	0.0025	0.000734	0.000193
γ_π	Uniform	0.5	0.289	0.368	0.194
γ_I	Uniform	0.5	0.289	0.221	0.102
δ	Uniform	0.5	0.289	0.388	0.0558
ρ_z	Beta	0.5	0.2	0.46	0.182
ρ_g	Beta	0.3	0.2	0.178	0.0805
σ_z	Gamma	0.01	0.01	0.00167	0.00149
σ_g	Gamma	0.01	0.01	0.00768	0.000907
R_{11}	Uniform	3.16e-06	1.82e-06	3.78e-06	1.75e-06
R_{22}	Uniform	2.1e-06	1.21e-06	3.77e-06	2.89e-07
R_{33}	Uniform	2.49e-07	1.44e-07	3.86e-07	9.42e-08
R_{44}	Uniform	9.68e-08	5.59e-08	1.36e-07	4.63e-08
χ				1.03	0.0938

Notes. The time unit is one quarter. The posterior distribution of χ is derived from the corresponding distribution of δ. The parameters R_{ii}, for $i = 1, \ldots, 4$ are the diagonal elements of the variance-covariance matrix of measurement errors.

Table C2: Estimation with the Twelve-Quarter Yield: Variance Decomposition

	α_ξ Estimated				$\alpha_\xi = 0$			
Shock	ΔI_t	$\Delta \Pi_t$	ΔY_t	ΔI_t^{12}	ΔI_t	$\Delta \Pi_t$	ΔY_t	ΔI_t^{12}
Permanent Monetary Shock, g_t^m	4	19	1	29	3	10	1	9
Preference Shock, ξ_t^c	25	2	0	43	39	52	8	82
Transitory Interest-Rate Shock, z_t^m	25	5	2	1	20	2	2	0
Preference Shock, ξ_t^h	36	57	41	22	29	28	37	7
Transitory Productivity Shock, z_t	6	10	2	3	5	5	2	1
Permanent Productivity Shock, g_t	4	7	55	2	3	3	50	1

Notes. Posterior means. Shares are expressed in percent. The variables ΔI_t, $\Delta \Pi_t$, and ΔY_t denote the change in the nominal interest rate, the change in the inflation rate, and the output growth rate. The last three columns display the variance decomposition under the counterfactual $\alpha_\xi = 0$ without reestimation.