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ARTICLE

A Note on the Neo-Fisher Effect in the New Keynesian Model*

Syed Zahid Ali[1,*] and Irfan A. Qureshi[2]

[1]Lahore University of Management Sciences (LUMS), Lahore, Pakistan
[2]Asian Development Bank (ADB), Metro Manila, Philippines
*Corresponding author. Email: szahid@lums.edu.pk

Abstract
Typically, contractionary monetary policy shocks increase the nominal and real rate of interest, which reduces both inflation and output . In contrast, the neo-Fisher effect (NFE) suggests that a transitory but persistent increase in the nominal rate of interest increases inflation in the short run. In a New Keynesian model augmented with several frictions, including the cost channel of monetary policy, real wage rigidity, habit formation in consumption, dampened expectations, and anticipated monetary policy shocks, we derive analytical conditions that give rise to (or avert) the NFE. We show that the NFE can arise due to the interplay between these frictions, and not only when the persistence of the policy shock is large, or when agents are forward-looking, as documented by the existing literature.

Keywords: Neo-Fisher effect; cost channel; anticipated shocks

1. Introduction

The one-to-one *long-run* relationship between the nominal interest rate and inflation is known as the Fisher effect. This relationship summarizes a central tenant of monetary economics in that the nominal rate of interest must catch up with inflation expectations in the long run to maintain a constant real rate. The textbook New Keynesian (NK) model, presented in Galí (2015), predicts that a temporary increase in the nominal rate of interest causes a contraction in the aggregate demand for goods in the short run, which lowers inflation and by extension, inflation expectations. With a credible persistent increase in the nominal rate of interest, expected inflation quickly adjusts to changes in the interest rate and gives rise to positive co-movement between nominal interest rate and inflation even in the short run (Uribe (2017)), termed the "neo-Fisher effect (NFE)."

This line of literature argues that when inflation is too low, as observed recently in many economies, the central bank should increase the short-term interest rate to raise the rate of inflation (Bullard (2010); Cochrane (2016); Williamson (2016)). This line of inquiry may contain important implications for the conduct of monetary policy, since it suggests that the current practice of lowering the interest rate in order to increase inflation may be counterproductive (Schmitt-Grohé and Uribe (2014); Garín et al. (2018)). Theoretically, the NFE occurs due to a permanent increase in the nominal interest rate (Cochrane (2016); Uribe (2017), (2022); García-Schmidt and Woodford (2019)) or due to a temporary but persistent increase in the nominal rate of interest in the short run through an inflation target shock (Garín et al. (2018)).

*The views expressed in this paper are those of the author and do not necessarily reflect the views of the Asian Development Bank (ADB), the Boards of Directors, or the countries it represents.

In this note, we study the short-run effect of a temporary but persistent increase in the nominal rate of interest on inflation and output. Our approach proposes a broader set of conditions that give rise to or avert the NFE. We develop a NK model that includes a cost channel, real wage rigidity, accounts for habit persistence in consumption, and includes two different type of agents' expectations and monetary policy shocks. The key takeaway from this note is that the NFE depends on: (i) structural factors (for instance due to the degree of cost channel, real wage rigidity, habit formation); (ii) the type of monetary policy shocks (unanticipated vs. anticipated) and type of monetary policy (interest rate persistence in the policy rule); and (iii) the type of expectations (standard vs. dampened).

Based on the richer transmission mechanism, several of our results contribute to the literature. For instance, the importance of the cost channel in conjunction with the degree of persistence of the shock, degree of price flexibility, forward-looking nature of the model, real wage rigidity, and anticipated interest rate shock is illustrated. In particular, we show that the NFE arises in the presence of a cost channel, working through the supply-side mechanism, which differs from the channels examined in García-Schmidt and Woodford (2019) and Cochrane (2016), who show that a permanent change in the nominal interest rate causes the NFE in NK models. We also demonstrate that the high degree of persistence in the monetary policy shock is not required in the presence of a cost channel, which enables us to mimic much of the dynamics of inflation and interest rates that give rise to the NFE observed in Garín et al. (2018).

The inclusion of habit persistence in household consumption (Fuhrer (2000)) and real wage rigidity (Blanchard and Galí (2007)) enrich our analytical insights. The inclusion of habit persistence helps avert the NFE arising from transitory but persistent monetary policy shocks. In the presence of the cost channel of monetary policy, and complete real wage rigidity, whether included separately or jointly, we note that there is a possibility for the occurrence of NFE. We also emphasize the importantance of expectations in giving rise to the NFE by augmenting our model to include dampened inflation and output expectations, following Gabaix (2016). This approach to model expectations is a departure from how expectations are formed in the models of Garín et al. (2018) and Cochrane (2016) and are shown to be more consistent with macroeconomic data.

The final thrust of our note focuses on the NFE through the lens of an anticipated monetary policy shock as opposed to an unanticipated monetary policy shock. When monetary policy is anticipated, a NFE emerges *irrespective of the structure of the model*. Intuitively, rational economic agents expect inflation at the outset as central bank announces credibly that it will change the interest rate in some future period. The higher expected inflation results in an increase in actual inflation, prior to the implementation of the policy, a result that converges with the findings of García-Schmidt and Woodford (2019). The NFE is amplified in the presence of a cost channel when monetary policy shocks are anticipated. Finally, simulations based on a calibrated general model to replicate business cycle moments in the USA confirm the analytical results presented in this note.

The rest of the note is organized as follows: Section 2 outlines the NK model, Section 3 presents closed-form solutions, while Section 4 presents simulations from the calibrated model. Section 5 concludes.

2. The Structural Framework

We closely follow Galí (2015) in setting up our structural framework. The model consists of three key equations: (i) a forward-looking IS curve, which accounts for habit persistence in consumption, (ii) a forward-looking Phillips curve, which accounts for both real wage rigidity and the cost channel of monetary policy, and (iii) a monetary policy reaction function.

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2.1. The demand side

We define consumer utility as a function of consumption C_t and hours worked, N_t, and maximize the utility of a representative agent with a standard budget constraint.[1] Log-linearizing the optimizing conditions yield the following relationships, with lower-case letters denoting the natural logarithm of the corresponding variables:

$$mrs_t = \frac{\sigma}{1-h}(c_t - hc_{t-1}) + \nu n_t \tag{1}$$

$$c_t = \frac{1}{1+h}E_t c_{t+1} + \frac{h}{1+h}c_{t-1} - \frac{(1-h)}{\sigma(1+h)}(i_t - E_t\pi_{t+1}) \tag{2}$$

where mrs_t is the marginal rate of substitution between consumption and hours worked, and $h \in (0, 1)$ measures (external) habit persistence. In equation (1), the parameter, ν, denotes the inverse of real wage elasticity of labor supply. Equation (2) suggests that current consumption is positively linked to lagged and future consumption and inversely related to real rate of interest $(i_t - E_t\pi_{t+1})$. Using the market clearing condition $(x_t = c_t)$ in (2), we derive the following equation of the forward-looking IS curve:

$$x_t = \frac{1}{1+h}E_t x_{t+1} + \frac{h}{1+h}x_{t-1} - \frac{(1-h)}{\sigma(1+h)}(i_t - E_t\pi_{t+1}) + u_t^x \tag{3}$$

where x_t is the logarithm of the output gap, $E_t\pi_{t+1} = E_t p_{t+1} - p_t$ is the expected inflation rate, p_t is the price of the good, and u_t^x is the demand shock. σ measures the intertemporal substitution of households or the degree of relative risk aversion.

2.2. The supply side

The key equation of the model is the forward-looking Phillips curve, derived in Galí (2015):

$$\pi_t = \chi E_t\pi_{t+1} + \lambda \text{rmc}_t \tag{4}$$

where rmc_t is the log of real marginal cost of the firm (which measures the cost of producing an extra unit of output), χ is the firm discount rate, and $\lambda = \frac{(1-\eta)(1-\chi\eta)}{\eta}$, where η is the proportion of firms which cannot change their prices (or the probability that a firm cannot change the price). The derivation of the Phillips curve is primarily based on Calvo (1983) and Galí and Gertler (1999); the key difference in our model is the inclusion of a cost channel of monetary policy (or supply-side effect of monetary policy). To do so, we assume that total real cost of the firm $\left(\frac{\text{TC}_t}{P_t}\right)$ captures the fact that firms may borrow money from financial intermediaries at the effective interest rate $(1 + i_t)^\theta$ to finance their wage bill, with the parameter θ measuring the strength of the cost channel:[2]

$$\frac{\text{TC}_t}{P_t} = \frac{W_t(1+i_t)^\theta N_t}{P_t} \tag{5}$$

From equation (5), we derive the following real marginal cost (RMC_t) equation:

$$\text{RMC}_t = \frac{W_t(1+i_t)^\theta}{\text{MPN}_t P_t} \tag{6}$$

where MPN_t is defined as the marginal productivity of labor. While the mechanism is intuitive, several studies have confirmed that the nominal interest rate factors into firms' cost of production. For instance, Ravenna and Walsh (2006), Tillmann (2008) and, more recently, Abo-Zaid (2020) find evidence of an active cost channel in the US economy and its impact on estimates of the government spending multiplier. Ravenna and Walsh (2006) estimate a range of values for the

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cost channel, θ, which were as low as 1.276 and as high as 11.831. Chowdhury et al. (2006) detect a cost channel in Canada, France, Italy, the UK, and the USA. Dedola and Lippi (2005) find evidence of a cost channel in France, Germany, Italy, and the UK, while Barth III and Ramey (2001) confirm these results. With $\text{mpn}_t = \ln \text{MPN}_t$ and $\text{rmc}_t = \ln \text{RMC}_t$, we derive the following relationship:

$$\text{rmc}_t = w_t - p_t + \theta \ln(1 + i_t) - \text{mpn}_t \tag{7}$$

Using the log-linear production function ($x_t = a_t + n_t$), where a_t measures log of technology, and $\ln(1 + i_t) \approx i_t$, we can write equation (7) as follows:

$$\text{rmc}_t = w_t - p_t + \theta i_t - \text{mpn}_t \tag{8}$$

Combining equations (4) and (8) gives us the following Phillips curve, where we assume $a_t = 0$ for convenience:

$$\pi_t = \chi E_t \pi_{t+1} + \lambda(w_t - p_t + \theta i_t) \tag{9}$$

Equation (9) derives the key mechanism in our model, which links the cost channel of monetary policy with current inflation, and plays an important role in determining the NFE as demonstrated by the analytical results in the next section.

Following Blanchard and Galí (2007) and Smith (2016), we further assume that real wages change sluggishly over time. Hall (2005) points out the importance of real wage rigidity to account for a number of important labor market facts. Blanchard and Galí (2007) document that the inclusion of real wage rigidity in the NK Phillips curve gives rise to a trade-off between stabilizing inflation and stabilizing the gap between output and desired output as perceived by most central banks, leading to the following equation:

$$w_t - p_t = \beta(w_{t-1} - p_{t-1}) + (1 - \beta) mrs_t \tag{10}$$

where $\beta = 0$ means complete real wage flexibility and $\beta = 1$ models complete real wage rigidity. Using equation (1) and the market equilibrium condition ($x_t = c_t$) in equation (10) and again setting $a_t = 0$, the real wage equation can be written as follows:

$$w_t - p_t = \beta(w_{t-1} - p_{t-1}) + (1 - \beta)\left(\frac{\sigma + \nu(1-h)}{1-h} x_t - \frac{\sigma h}{1-h} x_{t-1}\right) \tag{11}$$

Finally, combining (9) and (11) we arrive at the following forward-looking Phillips curve that includes both real wage rigidity (β) and a cost channel of monetary policy (θ):[3]

$$\pi_t = \chi E_t \pi_{t+1} + \lambda \left[\beta(w_{t-1} - p_{t-1}) + (1 - \beta)\left(\frac{\sigma + \nu(1-h)}{1-h} x_t - \frac{\sigma h}{1-h} x_{t-1}\right) + \theta i_t\right] \tag{12}$$

2.3. The monetary authority

We close our model by defining the monetary policy reaction function.[4] The central bank uses the short-term interest rate (i_t) to react to deviations of inflation and aggregate output from their respective targets. The inclusion of lagged interest rates gives rise to interest rate smoothing that replicates actual interest rate policy in many advanced economies (Galí (2015)). The parameter ξ is the smoothing coefficient of the short-term interest rate; ϕ^π is the responsiveness of the monetary authority to inflation, and ϕ^x is the coefficient on the output gap:

$$i_t = \xi i_{t-1} + (1 - \xi)(\phi^\pi \pi_t + \phi^x x_t) - u_t^i \tag{13}$$

Different from the inflation target shock considered in Garín et al. (2018), we study the impact of an expansionary unanticipated (or exogenous) monetary policy shock on the dynamics of interest rate, inflation, and output. We assume that the monetary policy shock follows an

AR(1) process, where $u_t^i = \rho u_{t-1}^i + \varepsilon_t$, enters with a negative sign in the policy rule to denote expansionary monetary policy, and $\varepsilon_t \sim N(0, \sigma_\varepsilon^2)$ and $\rho \in [0, 1)$. The parameter ρ measures the persistence in the monetary innovation shock. If $\rho = 0$, then the shock has no persistence and is purely stochastic; the shock is permanent when $\rho = 1$, but this in turn induces non-stationarity in u_t^i. Since the trajectory of all the endogenous variables depends on u_t^i, inflation and output gap also become non-stationary. To avoid the non-stationarity problem, we follow Garín et al. (2018) and solve the model to derive closed-form solution for stationary cases only (i.e., when $\rho \in [0, 1)$).

3. Analytical Results Based on Closed-Form Solutions

In this section, we derive the analytical conditions that give rise to and avert the NFE in the NK model, focusing first on the conditions under a standard unanticipated monetary policy shock and then deriving and analyzing conditions assuming anticipated monetary policy shocks.

3.1. Unanticipated monetary policy shocks

To focus on the main mechanisms, we rely on three assumptions: (i) no external habit persistence ($h = 0$), (ii) wages are perfectly flexible ($\beta = 0$), and (iii) central bank does not smooth interest rates ($\xi = 0$). These frictions are added back to the model in Section 4. Our model, then, simplifies to the following structural form:

$$x_t = E_t x_{t+1} - \frac{1}{\sigma}(i_t - E_t \pi_{t+1}) \tag{14}$$

$$\pi_t = \chi E_t \pi_{t+1} + \gamma_1 x_t + \gamma_2 i_t \tag{15}$$

$$i_t = \phi^\pi \pi_t + \phi^x x_t - u_t^i \tag{16}$$

$$u_t^i = \rho u_{t-1}^i + \varepsilon_t \tag{17}$$

where $\gamma_1 = \lambda(\nu + \sigma)$; $\gamma_2 = \lambda\theta$; $\lambda = \eta^{-1}(1 - \eta)(1 - \eta\chi)$; $\varepsilon \sim (0, \sigma_\varepsilon^2)$; $0 \leq \rho < 1$. To solve the model analytically, we assume the following trial solution:

$$x_t = a u_t^i; \pi_t = c u_t^i \tag{18}$$

Substituting equations (16) into (14) and (15), using the trial solution as given in (18), and finally using the method of undetermined coefficients, we derive the following set of restrictions on parameters a and c:

$$(\gamma_1 + \gamma_2 + \phi^x)a - (1 - \gamma_2\phi^x - \rho\chi)c = \gamma_2 \tag{19}$$

$$(1 + \sigma^{-1}\phi^x - \rho)a + \sigma^{-1}(\phi^\pi - \rho)c = \sigma^{-1} \tag{20}$$

Applying Cramer's rule on equations (19) and (20) and using the definition of the real rate of interest (i.e., $r_t = i_t - E_t \pi_{t+1}$), we derive the following multipliers:

$$\frac{dx_t}{du_t^i} = a = \frac{\sigma^{-1}[1 - \rho\chi - \lambda\theta\rho]}{\Delta} \tag{21}$$

$$\frac{d\pi_t}{du_t^i} = c = \frac{\lambda[\sigma^{-1}(\nu + \sigma) - \theta(1 - \rho)]}{\Delta} \tag{22}$$

$$\frac{di_t}{du_t^i} = \frac{\lambda(\nu + \sigma)\rho\sigma^{-1} - (1 - \rho)(1 - \rho\chi)}{\Delta} \tag{23}$$

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$$\frac{dr_t}{du_t^i} = \frac{(1-\rho)[\theta\lambda\rho - (1-\rho\chi)]}{\Delta} \tag{24}$$

$\Delta = (1+\sigma^{-1}\phi^x - \rho)(1-\rho\chi) + \sigma^{-1}\lambda(\nu+\sigma)(\phi^\pi - \rho) - \lambda\theta(\sigma^{-1}\rho\phi^x + \phi^\pi(1-\rho))$. We now focus on discussing the key mechanisms that give rise to and avert the NFE.

3.1.1. No cost channel of monetary policy

To first align the results of the baseline model with that of Garín et al. (2018), we illustrate the NFE with no cost channel. A key difference is that we consider an exogenous interest rate shock as compared to their inflation target shock.[5] One advantage of deriving their key results is to motivate how relaxing some of the underlying assumptions in their model can easily affect the existence of the NFE. Setting the cost channel, $\theta = 0$, in equations (21)–(24), we can show that the response of key macroeconomic variables to a monetary policy shock, $\frac{dx_t}{du_t^i} > 0$, $\frac{d\pi_t}{du_t^i} > 0$, $\frac{dr_t}{du_t^i} > 0$. With the assumption that $0 < \rho < 1$, we can also show that in the short run the nominal interest rate will increase and give rise to NFE if and only if the following condition holds:[6]

$$\frac{(\nu+\sigma)}{\sigma} > \frac{(1-\rho)(1-\rho\chi)}{\rho}\frac{\eta}{(1-\eta)(1-\eta\chi)} \tag{25}$$

We extract additional insights from condition (25) to study the existence of the NFE. For example, for any given value of η (which is the probability that a firm cannot change its prices, or a measure of price rigidity), if the shock is near permanent ($\rho \to 1$), then $\frac{(1-\rho)(1-\rho\chi)}{\rho} \to 0$, which implies that condition (25) is satisfied, that is, $\frac{(\nu+\sigma)}{\sigma} > 0$. This result is consistent with that of Garín et al. (2018) who argue that in the NK model, the NFE occurs if the shock to inflation target is highly persistent ($\rho > 0.60$).[7] Following Galí (2015), if we assume $\nu = \sigma = 1$ and $\eta = 0.70$, we can show that the NFE will occur for $\rho \geq 0.61$.

This result is also consistent with Schmitt-Grohé and Uribe (2014), who show that in a flexible price model, interest rate and inflation will co-move (i.e., the NFE) if the increase in the nominal interest rate is sustained for a prolonged period. When prices are almost rigid ($\eta \to 1$), condition (25) will not hold and will consequently contradict the neo-Fisher hypothesis as long as $\rho \neq 1$. To the contrary, if prices are almost perfectly flexible ($\eta \to 0$) and $\rho \neq 0$, condition (25) will also hold, a result consistent with Schmitt-Grohé and Uribe (2014). Extending these results, with *perfectly flexible prices*, inflation and interest rate move in the same direction even with low persistence in the monetary innovation shock. If we set $\nu = \sigma = 1$, then irrespective to the size of ρ and η, condition (25) will be satisfied automatically as long as $\rho = \eta$.

The key takeaway from this analysis is that in a simple model, which lacks key structural attributes such as the cost channel of monetary policy, habit persistence in consumption, interest rate smoothing policy of the central bank, etc., it is the persistence of the monetary innovation shock and the degree of price flexibility along with forward-looking nature of the agents, which give rise to NFE. In what follows, we argued that these structural factors, apart from the persistence of the monetary shock, may also give rise to or avert NFE.

3.1.2. Cost channel of monetary policy and the NFE

We now focus on the role of cost channel as one of the structural factors that can give rise to the NFE.[8] In the analysis below, we compare the role of the cost channel relative to the persistence of the monetary policy shock, connecting this particular mechanism with the NFE literature.

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Using equations (21) and (22),[9] we show that under condition (26), a decrease in the interest rate will lead to an increase in the rate of inflation (i.e., no NFE):[10]

$$\theta(1-\rho) < \frac{\nu+\sigma}{\sigma} < \frac{(1-\rho\chi)(1-\rho)}{\rho}\frac{\eta}{(1-\eta\chi)(1-\eta)} \tag{26}$$

The violation of condition (26) implies the existence of the NFE occurring if $\theta(1-\rho) > \frac{\nu+\sigma}{\sigma}$ or, in more detail, when $\frac{\nu+\sigma}{\sigma} > \frac{(1-\rho\chi)(1-\rho)}{\rho}\frac{\eta}{(1-\eta\chi)(1-\eta)}$, which suggests that the NFE in the NK model is much more pronounced in the presence of a cost channel ($\theta > 0$). A rise in the interest rate works through the supply side by increasing the marginal cost of firms that borrow to finance production, which leads to a contemporaneous increase in the current and the expected inflation. As the proportion of firms who borrow money to finance their production increases, the supply-side effects can potentially overwhelm the contractionary demand-side effects of the increase in the interest rate and give rise to inflation.

An interesting observation to note here is that even though the persistence of the shock gives rise to NFE in the baseline case, but in fact undermines the effect of cost channel of monetary policy – with higher shock persistence, the impact of cost channel of monetary policy on domestic inflation is muted. We note in condition (26) that in special case of permanent shock ($\rho = 1$), the cost channel is completely infused.

In principle, condition (26) makes the key point in that with a stronger cost channel, the NFE arises even for low persistence in monetary policy shocks. A key insight from this section is that NFE can also arise due to the presence of a cost channel, working through a mechanism that differs from earlier studies such as Uribe (2018), García-Schmidt and Woodford (2019), and Cochrane (2016), who show that a permanent change in the nominal interest rate causes the NFE in NK models. The high degree of persistence in the monetary policy shock is not required per se in the presence of a cost channel.

We also note the role of price rigidity in driving the NFE in the presence of a cost channel of monetary policy. From condition (26) if $\theta > \frac{\nu+\sigma}{\sigma(1-\rho)}$, the NK model yields the NFE even when prices tend to almost completely rigidity (as $\eta \to 1$). This result extends that found in Schmitt-Grohé and Uribe (2014) and Garín et al. (2018) who argue that NFE arises in a dynamic optimizing model with flexible prices when the interest rate increases for a prolonged period. On the contrary, our model suggests that if the supply-side effects are even calibrated at modest values (i.e, as long as they satisfy the following condition $\theta > \frac{\nu+\sigma}{\sigma}$), the NFE will occur.[11]

3.1.3. The role of real wage rigidity

A key point in Garín et al. (2018) is that NFE in the NK model is likely to occur when: (i) there is more persistent inflation rate target shock and (ii) prices are more flexible. Their discussion, however, is restricted only to cases when real wages are completely flexible, which may not be a very realistic assumption. For instance, Blanchard and Galí (2007) argue that real imperfections in the NK model (such as real wage rigidity) gives rise to a trade-off between inflation and unemployment, which is invariably faced by many central banks. Several other studies, such as Hall (2005), document the importance of real wage rigidity in business cycle models of the USA.

To discuss the implications of real wage rigidity in determining the NFE, we derive the following expressions for complete real wage rigidity, that is, when $\beta = 1$ in equation (12), with the cases of partial wage rigidity discussed in the simulations in Section 4:

$$\frac{d\pi_t}{du_t^i} = \frac{-\lambda\theta(1-\rho)}{(1-\rho\chi-\lambda\theta\phi^{\pi})(1-\rho+\sigma^{-1}\phi^x)+\lambda\theta\phi^x(\phi^{\pi}-1)} \leq 0 \tag{27}$$

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$$\frac{di_t}{du_t^i} = \frac{-(1-\rho)(1-\rho\chi)}{(1-\rho\chi-\lambda\theta\phi^\pi)(1-\rho+\sigma^{-1}\phi^x)+\lambda\theta\phi^x(\phi^\pi-1)} \leq 0 \tag{28}$$

From expressions (27) and (28), as long as there is some degree of cost channel, $\theta > 0$ and $0 \leq \rho < 1$, we observe a NFE. Thus, even with full real wage rigidity, we note a NFE in the presence of a cost channel.

An additional point here is that in this particular case, a negative shock to interest rate causes a contemporaneous decrease in both interest rate and the inflation rate. This result is true even for no persistence in the monetary policy shock ($\rho = 0$). However, in the absence of no cost channel of monetary policy, we note that a transitory monetary shock causes a decrease in the nominal rate of interest but has no impact on inflation.[12]

Finally, from equations (27) and (28), we note that irrespective to cost channel, in case of near permanent shock ($\rho = 1$), neither interest rate nor inflation will change. The result is different from Cochrane (2016) who argues that NFE in NK model arises if the interest rate shock is permanent. In sum, this section suggests that the inclusion of real wage rigidity is critical as far as the existence of the NFE is concerned.

3.2. Dampened expectations and the NFE

Expectations of inflation, in particular, the forward-looking nature of the NK model is a key feature that drives neo-Fisherism (Garín et al. (2018)). Recent work on inflation dynamics in the US and other advanced economies reveals that contemporaneous real variables such as output gap and employment have little impact on future inflation. In fact, inflation expectations, as found in data, do not commensurate with the prediction of NK Phillips curve, which depicts an almost one-to-one correspondence between the current inflation and the short-run inflation expectations (see, e.g., Kocherlakota (2016); Jorgensen and Lansing (2019)).[13] To account for this literature, we amend the baseline IS and Phillips curve as follows:

$$x_t = E_t x_{t+1} - \frac{1}{\sigma}(i_t - \hat{\psi} E_t \pi_{t+1}) \tag{29}$$

$$\pi_t = \chi\psi E_t \pi_{t+1} + \gamma_1 x_t + \gamma_2 i_t \tag{30}$$

where $0 < \hat{\psi} < 1$, $0 < \psi < 1$ are the dampened inflation expectation factors, following Gabaix (2016). With dampening factors, model expectations become less volatile and align better with real-world expectations, as noted in Gabaix (2016). For convenience, we assume that $\hat{\psi} = \phi\psi$ where $0 < \psi \leq 1$ (note that when $\psi = 1$, households and firms have same dampened inflation expectations factor). Using (29), (30), and the Taylor rule (16), we derive the following multipliers:

$$\frac{dx_t}{du_t} = \frac{\sigma^{-1}(1-\rho\psi\chi-\rho\psi\lambda\theta\phi)}{\Delta_1} \tag{31}$$

$$\frac{d\pi_t}{du_t} = \frac{\lambda[\sigma^{-1}(\nu+\sigma)-(1-\rho)\theta]}{\Delta_1} \tag{32}$$

$$\frac{di_t}{du_t} = \frac{\lambda(\nu+\sigma)\rho\phi\psi\sigma^{-1}-(1-\rho)(1-\rho\psi\chi)}{\Delta_1} \tag{33}$$

$$\Delta_1 = (1+\sigma^{-1}\phi^x-\rho)(1-\gamma_2\phi^\pi-\rho\psi\chi)+(\gamma_1+\gamma_2\phi^x)(\phi^\pi-\rho\phi\chi)\sigma^{-1}$$

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From (32), we note that if $\sigma^{-1}(\nu+\sigma) > (1-\rho)\theta$, inflation will increase and from (33), we note that under following condition interest rate will decrease which rules out the NFE:[14]

$$\psi = 1 \;\; if \;\; 1 < \frac{1-\rho}{\rho[\sigma^{-1}\lambda(\nu+\sigma)\phi + (1-\rho)\chi]} \;\; else \;\; \psi < \frac{1-\rho}{\rho[\sigma^{-1}\lambda(\nu+\sigma)\phi + (1-\rho)\chi]} \tag{34}$$

From (34), we can show that the rate of discount (ψ) and degree of persistence of the shock (ρ) are inversely related to each other. This outcome is quite intuitive. The higher persistence of the shock affects agents' expected inflation, which catches up with the changes in the nominal rate of interest and give rise to NFE. Augmenting the model with discounted expected inflation as per Gabaix (2016) breaks the close correspondence between the nominal rate of interest and expected inflation, and which averts the NFE. One special case is also seen in equation (34), that is in the event of near permanent increase in the nominal rate of interest ($\rho \approx 1$), the NFE in NK model arises for a theoretical feasible degree of dampened inflation expectation factor (ψ).

3.3. Anticipated monetary policy shocks

Existing studies on NFE assume that monetary policy and inflation target shocks are completely unanticipated. In practice, the central bank's (and government) policy changes are often well communicated, supporting the notion of at least partial anticipation in future policy changes. For instance, Blinder et al. (2008) argues that improved monetary policy communication since 1990s in the USA, has enhanced the predictability of monetary policy decisions, which has helped the monetary authority to achieve their macroeconomic objectives. Milani and Treadwell (2012) disentangle a monetary policy shock into a surprise and a news component, suggesting that (in relative terms) the news shocks have a much larger and more persistent effect on the economy.

Motivated by the work on anticipated shocks, (Ali & Qureshi, 2021) the second thrust of our contribution focuses on examining the NFE from the lens of an anticipated monetary policy shock. Without loss of generality, we assume that agents anticipate a change in the policy rate k-period in advance. To solve the model analytically, we assume the following trial solution:

$$x_t = \alpha^x + a\varepsilon_{t-k} \tag{35}$$

$$\pi_t = \alpha^\pi + c\varepsilon_{t-k} \tag{36}$$

$$\varepsilon_t = \rho\varepsilon_{t-1} + \nu_t; \;\; 0 \le \rho < 1, \quad \nu_t \sim \left(0, \sigma_\nu^2\right) \tag{37}$$

The first term on the right-hand side of each of the trial solutions illustrates the effect of the anticipated change in the policy rate on the corresponding variable at the time of announcement of the policy. The second term captures the effect of the actual change in the policy rate at the time of implementation of the policy (i.e., at time $t+k$). We solve the model for the case when $k=1$, that is, agents anticipate the shock one period in advance and that shock follows an AR(1) process as given by expression (37).[15] Using the method of undetermined coefficients, restrictions on the values of the parameters a, c, α^x, and α^π can be derived as follows, where agents anticipate a change in the policy rate of size m:

$$(\gamma_1 + \gamma_2\phi^x)a - (1 - \rho\chi - \gamma_2\phi^\pi)c = \gamma_2 \tag{38}$$

$$(1 + \sigma^{-1}\phi^x - \rho)a + \sigma^{-1}(\phi^\pi - \rho)c = \sigma^{-1} \tag{39}$$

$$(\gamma_1 + \gamma_2\phi^x)\alpha^x - (1 - \chi - \gamma_2\phi^\pi)\alpha^\pi = -\chi cm \tag{40}$$

$$\phi^x\alpha^x + (\phi^\pi - 1)\alpha^\pi = (\sigma a + c)m \tag{41}$$

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We solve this system of equations in two stages. First, after solving equations (38) and (39) simultaneously, we assign values to a and c that are the same as that derived in the case of unanticipated shock. Using these expressions in (40) and (41) yield the values of α^x and α^π. It is worth noting here that the on-impact effect of the announced policy on output, inflation, and the interest rate depend on the effects of the policy at the time of execution. Using (38)–(41), we derive the following multipliers:

$$\frac{d\alpha^x}{dm} = \frac{(1-\rho(\chi+\lambda\theta))(1-\chi-\lambda\theta\phi^\pi)+\lambda(1-\phi^\pi(\chi+\lambda\theta))(\sigma^{-1}(\nu+\sigma)-\theta(1-\rho))}{\Delta\Theta} \tag{42}$$

$$\frac{d\alpha^\pi}{dm} = \frac{\lambda(\nu+\sigma)[1-\rho\chi+\sigma^{-1}\lambda(\nu+\sigma)+\sigma^{-1}\phi^x\chi]+\lambda\theta[\sigma^{-1}\lambda(\nu+\sigma)(\phi^x-\sigma)+\phi^x(1-\chi-\lambda\theta)]}{\Delta\Theta} \tag{43}$$

$$\frac{d\alpha^i}{dm} = \frac{\phi^x[\lambda\sigma^{-1}(\nu+\sigma)+(1-\rho\chi)(1-\chi-\lambda\theta)]+\phi^\pi\lambda(\nu+\sigma)[1-\rho\chi-\lambda\theta+\sigma^{-1}\lambda(\nu+\sigma)]}{\Delta\Theta} \tag{44}$$

$\Delta = (1+\sigma^{-1}\phi^x-\rho)(1-\rho\chi)+\sigma^{-1}\lambda(\nu+\sigma)(\phi^\pi-\rho)-\lambda\theta(\sigma^{-1}\rho\phi^x+\phi^\pi(1-\rho))$ $\Theta = \lambda(\nu+\sigma)(\phi^\pi-1)+\phi^x(1-\chi-\lambda\theta)$

Under an anticipated shock, the model yields the NFE even without a cost channel of monetary policy and without any minimum degree of shock persistence (see equation (45) below). Note that this outcome is quite different from the case when the shock is unanticipated (or exogenous). In the presence of cost channel, however, the signs of the derived multipliers depend on the parameter values of the model.

$$\frac{d\alpha^\pi}{dm} > 0, \quad \frac{d\alpha^x}{dm} > 0, \quad \frac{d\alpha^i}{dm} > 0 \tag{45}$$

Using standard values used in the literature, such as $\nu = \sigma = 1$, $\rho = \eta = 0.70$, $\chi = 0.99$ and different values of parameter $\theta \in (0, 1, 1.5, 2, 2.5)$, an anticipated expansionary monetary shock invariably causes an increase in both the interest rate and the inflation rate at the time of announcement of the policy. Therefore, when the monetary shock is anticipated, the NK model yields NFE *irrespective of the structure of the model*. Intuitively, rational economic agents expect inflation at the outset as central bank announces credibly that it will change the interest rate in some future period. The higher expected inflation results in an increase in actual inflation, prior to the implementation of the policy.

The direction of the impact on output depends on the values of cost channel (θ) and monetary policy shock persistence (ρ). For $\rho = 0$, output increases even for a relatively higher value of θ (e.g., $\theta = 2.5$). But for $\rho \geq 0.60$ with $\theta = 2.5$, output decreases. In general, we find that output decreases for relatively higher values of ρ.[16]

4. Quantitative Analysis

In order to glean further insights from our analytical results, we simulate the general model for a set of plausible parameter values chosen to match moments observed in a large economy, such as the USA. Following Blanchard and Galí (2007), we set $\beta = 0.90$ which implies a half-life for the adjustment of the real wage of about six periods, but we also consider several other values to illustrate the role of real wage rigidity in giving rise to a NFE. As far as the monetary policy rule is concerned in equation (13), we set the smoothing parameter, $\xi = 0.75$. We also set $\phi^x = 0.5$ and

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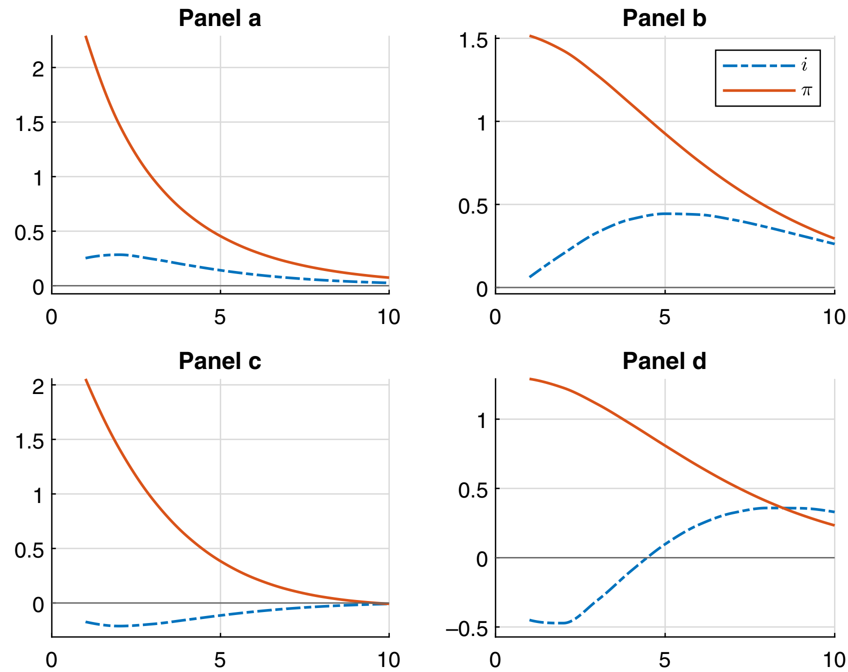

Figure 1. Impulse responses to a one standard deviation unanticipated shock to the policy rate with no cost channel. (a) $\rho = 0.70$, $\xi = 0.75$, $\theta = 0$, $\beta = 0$, $h = 0$. (b) $\rho = 0.70$, $\xi = 0.75$, $\theta = 0$, $\beta = 0.90$, $h = 0$. (c) $\rho = 0.70$, $\xi = 0.75$, $\theta = 0$, $\beta = 0$, $h = 0.90$. (d) $\rho = 0.70$, $\xi = 0.75$, $\theta = 0$, $\beta = 0.90$, $h = 0.90$.

$\phi^{\pi} = 1.5$ which are common values (see Galí, 2015) and mimic well the behavior of historical US monetary policy, at least prior to the Great Recession. We generate impulse responses with and without the cost channel of monetary policy.

4.1. No cost channel of monetary policy

We illustrate the simulations from the general model, focusing first on the case with no cost channel. Figure 1 plots the impulse response functions of inflation and interest rate to a one standard deviation unanticipated shock to the policy rate.

The upper two panels of Figure 1(a and b) depict the two cases where we observe a NFE, whereas the lower sub-figures (c and d) highlight those combinations of parameter values which eliminate the NFE from our results. It is evident that in the absence of habit persistence ($h = 0$) in consumption, no real wage rigidity ($\beta = 0$), and in the presence of interest rate smoothing ($\xi = 0.75$), the NFE occurs due to a relatively high persistence in the shock (see Figure 1a). We continue to observe NFE even with a high degree of real wage rigidity ($\beta = 0.90$) but with no habit persistence in consumption (see Figure 1b). The NFE, however, disappears when we assume a high degree of habit persistence in consumption ($h = 0.90$) irrespective of the level of real wage rigidity ($\beta = 0$ or $\beta = 0.90$).[17]

In the absence of cost channel of monetary policy, the monetary policy shock becomes a purely demand-side phenomenon and habit persistence in consumption, simply makes this shock less effective. The key takeaway from the simulations so far is that—in the absence of cost channel of monetary policy—habit persistence in consumption can be sufficient to remove the NFE in the NK model. From this result, an additional conclusion is that averting the NFE may *not* only be contingent upon a certain mass of backward-looking firms in the model as suggested by

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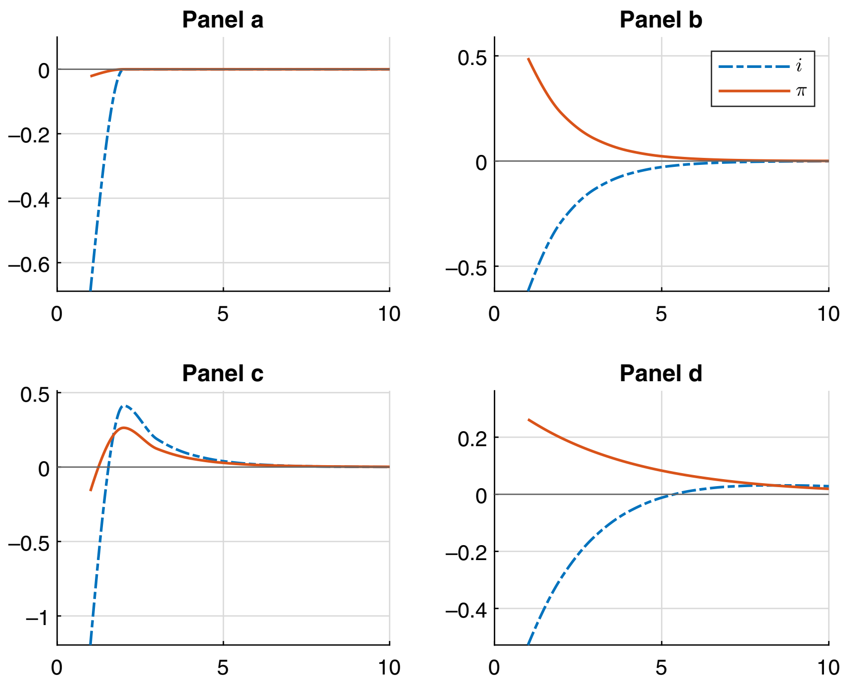

Figure 2. Impulse responses to a one standard deviation shock to the policy rate with cost channel.
Notes: In this figure, we plot the responses of inflation and interest rates to a to a one standard deviation shock to the policy rate with cost channel using different values of the structural parameters. (a) $\rho = 0$, $\xi = 0$, $\theta = 2.2$, $\beta = 0$, $h = 0$, $v = 1$. (b) $\rho = 0$, $\xi = 0.75$, $\theta = 2.2$, $\beta = 0$, $h = 0$, $v = 1$. (c) $\rho = 0$, $\xi = 0$, $\theta = 2.2$, $\beta = 0.90$, $h = 0.90$, $v = 2$. (d) $\rho = 0.70$, $\xi = 0$, $\theta = 2.2$, $\beta = 0$, $h = 0.90$, $v = 1$.

Garín et al. (2018) but can be eliminated in a more general model setting as well, such as one that includes habit formation in consumption.

4.2. Cost channel of monetary policy

We now simulate the importance of the cost channel in determining the interest rate and inflation linkages. To do so, we assume that all firms borrow money at the market rate of interest.

In Figure 2, we note that under modest values of the cost channel ($\theta = 2.2$), we observe the NFE even when the unanticipated monetary policy shock is purely stochastic or transitory. Recall the condition (26) under which there will be no NFE in the presence of cost channel of monetary policy: $\theta(1-\rho) < \frac{\nu+\sigma}{\sigma} < \frac{(1-\rho\chi)(1-\rho)}{\rho}\frac{\eta}{(1-\eta\chi)(1-\eta)}$. For $\rho \to 0$, this condition can be violated easily for $\theta > 2$ given the fact that we assume $\nu = \sigma = 1$. On the other hand, we can note that as ρ increases, since the right-hand side of the condition is difficult to hold, that is, $\frac{\nu+\sigma}{\sigma} < \frac{(1-\rho\chi)(1-\rho)}{\rho}\frac{\eta}{(1-\eta\chi)(1-\eta)}$, the model entails the NFE.

This result holds without any habit persistence in consumption and real wage rigidity, the combination of which yield very different results in a scenario without a cost channel. In Figure 2b, we note that NFE disappears once we assume interest rate smoothing by the central bank, which seem to tame individual expectations. Interestingly enough, for $\rho \to 0$, we note that the NFE persists if we assume habit persistence in consumption and real wage rigidity ($h > 0$, $\beta > 0$) but no interest rate smoothing ($\xi = 0$). For $h > 0$, $\beta = 0$, the NFE emerges even for $\nu \geq 2$ (see Figure 2c). Conditional on the persistence of the shock, the role of parameter h is much more profound in averting the NFE (Figure 2d).

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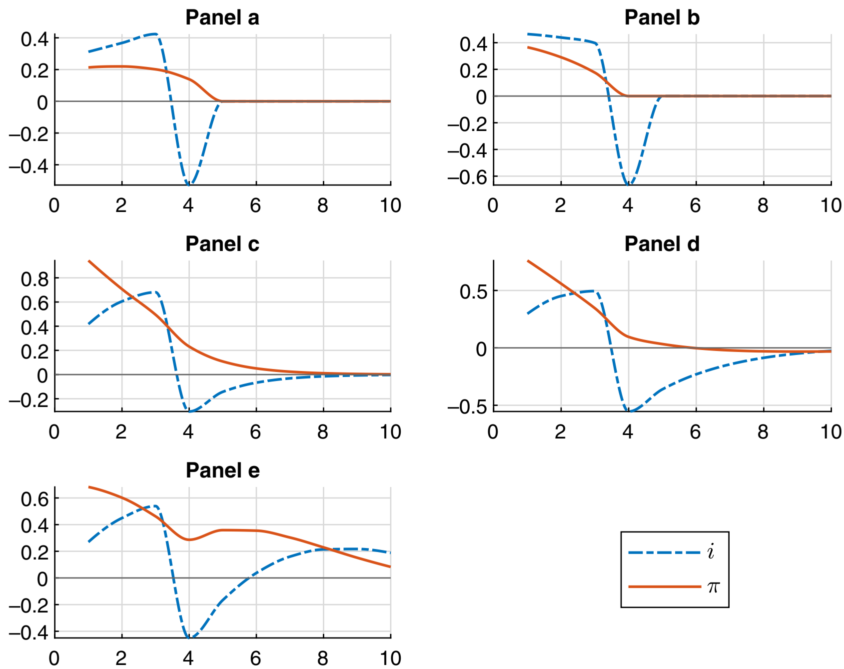

Figure 3. Impulse response of the interest rate and inflation to an anticipated monetary expansionary shock.
Notes: In this figure, we plot impulse response of the interest rate and inflation to an anticipated monetary expansionary shock. We set $k = 3$, which controls the periods in advance agents expect the shock to the policy rate. As before, we use different values of the structural parameters. (a) $\rho = 0, \xi = 0, \theta = 0, \beta = 0, h = 0, v = 1$. (b) $\rho = 0, \xi = 0, \theta = 2.2, \beta = 0, h = 0, v = 1$. (c) $\rho = 0, \xi = 0.75, \theta = 2.2, \beta = 0, h = 0, v = 1$. (d) $\rho = 0, \xi = 0.75, \theta = 2.2, \beta = 0, h = 0.90, v = 1$. (e) $\rho = 0, \xi = 0, \theta = 2.2, \beta = 0.90, h = 0.90, v = 1$.

The key outcome from the simulation exercises in a more general model is that in the presence of cost channel, it is difficult to avoid the NFE but which, as demonstrated throughout this note, it can be easily averted in a standard model that includes additional frictions. In particular, we show that two parameters, that is, the degree of interest rate smoothing (ξ) and the intensity of habit persistence in consumption (h) are important in averting the NFE. In short, when the monetary policy shock is purely stochastic ($\rho = 0$) and real wages are not rigid ($\beta = 0$), a higher value of ξ is required. When the monetary policy shock persistence is relatively high ($\rho > 0.60$), a higher value of habit formation h defuses the NFE. Intuitively, habit persistence in consumption weakens the sensitivity of aggregate demand to changes in the real rate of interest and also affects the dynamics of the inflation stemming from the Phillips curve, which eventually helps in diminishing the NFE.

4.3. Anticipated monetary policy shocks

The results for an expansionary monetary policy shock, which is anticipated by the agents three periods in advance, are reported in Figure 3. We simulate the baseline model which does not include either cost channel or habit persistence in consumption or real wage rigidity. In subsequent panels, we relax these assumptions and simulate the general model including these frictions.

Figure 3 reports the results with $\rho = 0$, which unravels the role of an anticipated shock in the determination of NFE. We note that on impact, both inflation and the interest rate increase. In the subsequent periods, apart from the Panel B, interest rate increases but inflation falls. Once the

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policy is implemented (at period 3), interest rate and inflation both fall at the same time for all cases.

These results hold regardless of the different degrees of real wage rigidity, cost channel, various intensities of habit persistence, and interest rate smoothing by the central bank.[18] Our main finding is that under an anticipated shock, the model always yields a NFE, both in the impact period and at the time of implementation of the policy, that is, period 3 in this particular case to illustrate the key model results, but can apply to more general values.

5. Conclusion

This note derives and illustrates analytical conditions that give rise to or avert the NFE in a NK model. We include several frictions to augment the textbook version of the model, the combination of which can, at least theoretically, rationalize the NFE. Particularly, we include a cost channel of monetary policy, habit persistence in consumption, real wage rigidity, and dampened expectations. We also study the NFE from the lens of an anticipated monetary policy shock.

We show that the NFE arises in the presence of a cost channel, working through a mechanism that differs from earlier studies such as those taken in Uribe (2018), García-Schmidt and Woodford (2019), and Cochrane (2016). We demonstrate that the high degree of persistence in the monetary policy shock is not required per se in the presence of a cost channel, enabling us to mimic much of the dynamics of inflation and interest rates that give rise to the NFE observed in Garín et al. (2018). We also illustrate how the supply-side mechanisms links with forward-looking expectations—a key ingredient required to give rise to NFE in Garín et al. (2018)—by examining the case when agents discount expectations, as proposed by Gabaix (2016), and which may be consistent with macroeconomic data. The inclusion of habit persistence in consumption and real wage rigidity assumption further enriches our analytical results.

Irrespective of the structure of the model, an anticipated monetary policy shock always gives rise to a NFE. Our simulation exercises, which are based on a more general model, further show that in case of unanticipated shock, the inclusion of habit persistence in consumption and interest smoothing policy of the central bank both contribute to averting the NFE, despite the presence of a cost channel of monetary policy and a persistent monetary policy shock.

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Notes

1 The utility function is described as $U_t = E_0 \sum_{t=0}^{\infty} \omega^t \left[\frac{(C_{t+\tau} - hC_{t+\tau-1})^{1-\sigma}}{1-\sigma} - \frac{N_{t+\tau}^{1+\nu}}{1+\nu} \right]$ and the period budget constraint is given as $P_t C_t + M_t + \frac{B_t}{1+i_t} \leq M_{t-1} + B_{t-1} + W_t N_t + T_t$, where $0 < \omega < 1$ is discount rate, B_t is one period bond, which entail one dollar per bond, and T_t is a lump-sum tax.

2 The effective interest rate $(\hat{i}_t)$ and the risk-free interest rates (i_t) are linked together as $1 + \hat{i}_t = (1 + i_t)^{\theta}$. Log-linearization of this relationship yields $\hat{i}_t = \theta i_t$. If $\theta = 1$, then the effective and risk-free interest rates are the same. On the other hand, if $\theta > 1$ then, owing to friction in financial markets, the borrowing rate is higher than the lending rate. Note that the existing literature also presents an alternative interpretation for the parameter θ, representing the fraction of firms that borrow funds (Rabanal (2007)) or the fraction of the wage bill that is financed through borrowing (Ali and Anwar (2016, 2018); Phaneuf et al. (2018); Qureshi and Ahmad (2021)). Either of these interpretations imply that $\theta \in [0, 1]$. However, interpreting θ as the strength of the cost channel, as in Tillmann (2008), leads to the possibility of θ being greater than one Chowdhury et al. (2006).

3 In the case of $\beta = h = \theta = 0$, equation (12) collapses to the textbook NK closed economy Phillips curve presented in Galí (2015).

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4 Note that the model does not include money aggregates, which have been showing by Qureshi (2020) to be economically and statistically significant during the Volcker–Greenspan era. Intuitively, including money aggregates simply makes the policy rule more inflation averse, which does not affect the main results of this paper.
5 Garín et al. (2018) focuses on strict inflation targeting policy of central bank ($\phi^{\pi} \longrightarrow \infty$), whereas we assume that central bank follows a flexible inflation targeting policy as described by the monetary policy rule (see equation (16)). Finally, while the main mechanism driving the NFE in Garín et al. (2018) is through a shock to the inflation target, we derive our results through a more standard mechanism, that is, through an exogenous monetary policy shock (u_t^i).
6 From (23), we note that if $\rho > 0.5\chi^{-1}(1+\lambda\sigma^{-1}(\nu+\sigma)+\chi-\sqrt{(1+\lambda\sigma^{-1}(\nu+\sigma)+\chi)^2-4\chi})$ then an increase in nominal rate of interest would cause an increase in rate of inflation.
7 Uribe (2018), Schmitt-Grohé and Uribe (2014), and Cochrane (2016), on the other hand, argue that NFE will occur if central bank increases (decreases) the interest rate permanently, that is, inflation will increase (decrease) if interest rate increases (decreases) permanently.
8 While the cost channel of monetary policy has been studied extensively in the price puzzle literature, its applications in relation to monetary policy shock persistence remains limited. For instance, in that line of literature, it is often assumed that shock to the interest rate is purely stochastic, which does not pose any ambiguity in the direction of change in the interest rate.
9 Closer inspection of equations (22) and (23) reveal that in the presence of cost channel, there are two possible cases that do not classify as the NFE. Case I (II) is when a decrease (increase) in the interest rate causes an increase (decrease) in the inflation rate. Case I is a situation where the demand side effects of a decrease in the interest rate dominate the supply-side effects of the interest rate, which increase the inflation rate, a condition also supported by the models' stability conditions. We learn through our simulation exercises that Case II is not consistent with the stability of our model as also discussed in Cochrane (2016). He studies the possibility of the NFE by analyzing a contractionary monetary policy shock and learned that the equilibria, which is consistent with increasing inflation with increasing interest rate, is more plausible than the alternative. In our case, since we are analyzing an expansionary MP shock, we note that the equilibria in which a decrease in the interest rate gives rise to a decrease in the inflation is more plausible than the alternative. For model stability reasons, we focus only on Case I possibility henceforth.
10 We derive (26) under the condition: $\Delta = (1+\sigma^{-1}\phi^{\pi}-\rho)(1-\rho\chi)+\sigma^{-1}\lambda(\nu+\sigma)(\phi^{\pi}-\rho)-\lambda\theta(\sigma^{-1}\rho\phi^{\pi}+\phi^{\pi}(1-\rho))>0$. We note that Δ will be negative only if η is very low (i.e., a very high value of λ), under which prices are perfectly flexible. Price flexibility of such order indeed lack empirical evidence.
11 From (26), we document that for a given value of ρ and θ, the NFE is less likely to occur for relatively higher value of ν (inverse of real wage elasticity) and relatively low value of σ (intertemporal substitution of household). Note that this follows relatively straightforward intuition: in the π_t, x_t space, the IS curve is negatively sloped but the Philips curve is positively sloped for standard parameter values (see, Galí (2015)). The IS curve shifts rightward in the event of monetary shock. In the presence of cost channel of monetary policy, the Phillips curve will also shift rightward due to policy shock and ease out some inflationary pressure. With higher ν, the Phillips curve will be steeper and will shift relatively less toward the right as interest rate decreases. In the case of a monetary policy shock, the shift in the IS curve will be more than the shift in the Phillips curve and causes inflation if $(\nu+\sigma)\sigma^{-1} > \theta(1-\rho)$. This condition is more likely to hold if ν takes a higher value and σ takes a smaller value, ceteris paribus.
12 Note that, we can impose complete real wage rigidity by setting $\beta = 1$ in equation (12). In this case, our Phillips curve reduces to $\pi_t = \chi E_t\pi_{t+1} + \lambda\theta i_t$. If $\theta = 0$, the Phillips curve will be independent to rest of the model and inflation will be determined only by the next period expected inflation. From $\pi_t = \chi E_t\pi_{t+1}$, while using lead variable B^{-1}, we can show that $E_t(1-\chi B^{-1})\pi_t = 0$ which implies that $\pi_t = 0\ \forall t$. We can also note that in case of static expectations ($E_t x_{t+1} = 0$) and real wage rigidity, we do observe NFE $\frac{d\pi_t}{di_t} = \lambda\theta \geq 0$ as $\theta \geq 0$. In contrast, if agents form expectations rationally, then in this case we can show that $\pi_t = \lambda\theta E_t \sum_{j=0}^{\infty} \chi^j i_{t+j}$, that is, due to cost channel, current inflation depend on current and future expected interest rates.
13 Using our trial solution (18) we can show that $E_t\pi_{t+1} = \rho\pi_t$, that is, expected inflation move almost in one-to-one fashion with current inflation when $\rho \rightarrow 1$.
14 As before, we omit case II where interest rate increases but inflation decreases due to stability reason of the model.
15 Milani and Treadwell (2012) found that a 1-year anticipation horizon plays most significant role in determining the impact of an anticipated shock.
16 We also confirm the sensitivity of our results to real wage rigidity and static and dampened expectations. When real wage rigidity assumption is combined with dampened expectations only then for relatively higher values of ρ and the dampened factor ψ, such that $\psi \geq \rho$, the model is free of the NFE. Nevertheless, this result is not robust. Similarly, with real wage rigidity, output decreases on impact when $\rho \geq \eta$, that is, persistence in the shock is greater than probability of change in the price; however, this result is also not robust. Generally speaking, under an anticipated expansionary monetary policy shock, the model is neo-Fisherian regardless of the presence of the cost channel of monetary policy or the persistence of the shock.
17 As per Taylor's rule in equation (13), the central bank tends to increase (decrease) the nominal rate of interest whenever current inflation and current output increase (decrease) from their target levels so that both variables stay as close as possible to their respective targets. At the time of the shock, we set all the variables at their steady state level, that is, $x_t = \pi_t = i_t =$

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$i_{t-1} = u_t^i = 0 \; \forall \; t$. For example, in the event of monetary innovation shock (increase in u_t), except i_{t-1}, all variables change and effect i_t contemporaneously. An increase in u_t puts negative pressure on i_t. At the same time, as we depict in our closed-form solution, for example, in the absence of cost channel of monetary policy and no interest rate smoothing ($\xi = 0$), both output and inflation will increase (see equations (21) and (22) above) which put positive pressure on i_t. In this situation, the impact of the shock on i_t is ambiguous, that is, $\frac{di_t}{du_t^i} = \phi^\pi \frac{d\pi}{du_t^i} + \phi^x \frac{dx_t}{du_t^i} - 1 \gtrless 0$. If the combined effect of x_t and π_t on i_t dominate (fall short to) the effect of u_t^i on i_t, then i_t will increase (decrease). In Figure 1, we noticed that (excluding habit persistence in consumption for brevity) the interest rate increases in the event of interest rate shock but decreases in the presence of relatively high degree of habit persistence for the same shock. The intuition behind these results run as follows: in the presence of habit persistence in consumption, the effect of interest rate shock on demand side of the model reduces considerable which lowers the impact of the shock on both output and inflation. Consequently, the monetary authority does not increase the rate of interest by much to control output and inflation around their respective targets. As a result, we do see a net fall in the rate of interest on impact and rise in the inflation rate, that is, no NFE. In contrast, in the absence of habit persistence in consumption, the impact of the shock on both output and inflation is quite high and the monetary authority ends up increasing the net rate of interest to control both the variables at their study state level. In this case, we do observe NFE.

18 To test the sensitivity of our results under different shock persistence, we simulate the model for $\rho = 0.70$ and 0.90 and learn that results do not change qualitatively.

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