Heterogeneous Downward Nominal Wage Rigidity: Foundations of Phillips's Phillips Curve*

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This draft June 30, 2023

Abstract

We introduce a form of downward nominal wage rigidity that can vary in intensity across a continuum of labor varieties. The model delivers a static wage Phillips curve linking current wage inflation to current unemployment. For standard parameterizations, the dynamics of the model are qualitatively and quantitatively similar to those of the new-Keynesian model with wage stickiness, which features a forward-looking wage Phillips curve, linking current wage inflation to future expected wage inflation and current unemployment. This result puts in perspective the role played by the forward-looking component of the new-Keynesian wage Phillips curve. A convenient property of the proposed model is that it is amenable to perturbation analysis because although it features occasionally binding constraints at the level of individual labor types it does not have such constraints at the aggregate level.

Keywords: Downward nominal wage rigidity, wage Phillips curve, new-Keynesian model, heterogeneity.
JEL Classification: E24, E31, E32.

*We thank Francisco Ciocchini for helpful comments and Giovanni Bonfanti for superb research assistance.
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1 Introduction

Since its conception in 1958, the Phillips curve has been the focus of intense research activity in Macroeconomics. In its original formulation, Phillips (1958) conceived it as a contemporaneous empirical relationship between wage inflation and unemployment. The new-Keynesian model, which has arguably been the predominant framework for economic analysis since the 1990s, introduces a forward-looking component into the Phillips curve. In this class of models, wage inflation is related not only to the rate of unemployment but also to future expected wage inflation. This paper addresses two related questions. First, is the forward-looking component in the wage Phillips curve a necessary feature of models with nominal rigidity and forward-looking rational agents? And second, if not, would a model featuring a static wage Phillips curve have significantly different dynamic properties?

We propose a model in which downward nominal wage rigidity varies in intensity across a continuum of labor varieties. The nominal wage of each labor variety is bounded below by the average wage prevailing in the previous period times a variety-specific scalar. In all respects other than the heterogeneity of downward nominal wage rigidity, the model economy is standard; households and firms operate in competitive markets and are rational and forward looking. We show that in equilibrium the model delivers a static wage Phillips curve. An increase in wage inflation raises the fraction of labor varieties that are not constrained by the wage lower bound. As a result, the fraction of the labor force suffering involuntary unemployment falls. Taken together, these effects imply a negative contemporaneous relationship between current wage inflation and current unemployment. The model thus provides a foundation to Phillips's celebrated static empirical relation.

A second important result of the paper is that for standard calibrations of the model, its implied equilibrium dynamics are qualitatively and quantitatively similar to those of the new-Keynesian model of wage stickiness. A corollary of this result is that the forward-looking component in the wage Phillips curve, which is a key characteristic of the new-Keynesian framework, does not appear to play a crucial role in shaping its dynamic properties.

A convenient characteristic of the proposed model with heterogeneous downward nominal wage rigidity is that it is amenable to perturbation analysis, which facilitates computation of the equilibrium dynamics. The standard model of downward nominal wage rigidity, in which the stringency of the wage lower bound is homogeneous across workers, features an occasionally binding constraint in equilibrium, which complicates the computation of the equilibrium dynamics. In the proposed model, although there are occasionally binding constraints at the level of individual labor varieties, in the aggregate the equilibrium conditions do not feature such restrictions.

This paper is related to a large literature on the role of nominal wage rigidity for macroeconomic adjustment. This body of work is too vast to allow for an exhaustive review, so we are necessarily, and most likely unfairly, selective. As mentioned, the starting point is the empirical estimate by Phillips (1958) of a negative relation between wage inflation and unemployment. In the context of the new-Keynesian framework, sticky wages à la Calvo was introduced by Erceg, Henderson, and Levin (2000). The derivation of a wage Phillips curve in the context of that model is presented in Galí (2011) and Casares (2010). These authors show that the implied wage Phillips curve is forward looking. The implications of downward nominal wage rigidity for macroeconomic adjustment in dynamic general equilibrium models is studied in Benigno and Ricci (2011) and in Schmitt-Grohé and Uribe (2016, 2017). Unlike in the present formulation, in these studies the lower bound on nominal wages is invariant across labor varieties. The framework proposed here nests this class of model as a special case. There is also a literature combining labor search frictions and nominal rigidities including Faia (2008), Gertler, Sala, and Trigari (2008), and Dupraz, Nakamura, and Steinsson (2022). Relative to this literature the present paper does not consider search frictions. Instead the source of involuntary unemployment is a labor variety specific form of downward nominal wage rigidity.

The empirical relevance of downward nominal wage rigidity has been extensively documented by, among others, Card and Hyslop (1996), Kahn (1997), Gottschalk (2005), Barattieri, Basu, and Gottschalk (2014), Daly and Hobijn (2014), Schmitt-Grohé and Uribe (2016), and Jo (2022). Finally, empirical estimates of the wage Phillips curve are presented in Galí (2011) and Galí and Gambetti (2019). We use the latter of these two papers to discipline our quantitative analysis.

The remainder of the paper is organized as follows. Section 2 presents the model with heterogeneous downward nominal wage rigidity. This section also shows that the equilibrium conditions do not include occasionally binding constraints, allowing for a characterization of the equilibrium using perturbation methods. Section 3 analyzes the short- and long-run Phillips curves implied by the proposed model. Section 4 shows that for standard calibrations the equilibrium dynamics implied by the model with heterogeneous downward nominal wage rigidity are similar to those of the new-Keynesian model of wage rigidity. Section 5 concludes.

2 The Model

To focus on the modeling of heterogeneous downward nominal wage rigidity, we first present an economy with inelastic labor supply.

2.1 Firms

Firms are price takers. They use labor as the sole input to produce a final good. Profits are given by

$$P_t z_t F(h_t) - W_t h_t,$$

where P_t denotes the product price level, h_t denotes labor, W_t denotes the nominal wage rate, z_t is an exogenous productivity shock, and $F(\cdot)$ is an increasing and concave production function. The optimality condition determining the demand for labor is

$$z_t F'(h_t) = \frac{W_t}{P_t}, \tag{1}$$

which equates the marginal product of labor to the real wage.

The labor input h_t is assumed to be a composite of a continuum of labor varieties h_{jt} for $j \in [0, 1]$. The aggregation technology is of the form

$$h_t = \left[\int_0^1 h_{jt}^{1-\frac{1}{\eta}} dj\right]^{\frac{1}{1-\frac{1}{\eta}}}, \tag{2}$$

where $\eta > 0$ is the elasticity of substitution across labor varieties. The firm chooses the quantity of each labor variety h_{jt} to minimize its total labor cost, $\int_0^1 W_{jt} h_{jt} dj$, subject to the aggregation technology (2), given its desired amount of the labor composite h_t and taking as given the wage of each variety of labor, denoted W_{jt}. This cost minimization problem yields the demand for labor of type j,

$$h_{jt} = \left(\frac{W_{jt}}{W_t}\right)^{-\eta} h_t, \tag{3}$$

where

$$W_t = \left[\int_0^1 W_{jt}^{1-\eta} dj\right]^{\frac{1}{1-\eta}} \tag{4}$$

is the cost-minimizing price of one unit of aggregate labor, that is, when h_{jt} is chosen optimally, W_t satisfies $W_t h_t = \int_0^1 W_{jt} h_{jt} dj$. Firms are assumed to be always on their demand schedules for labor varieties.

2.2 Households

The representative household has preferences over streams of consumption, denoted c_t, described by the utility function

$$E_0 \sum_{t=0}^{\infty} \beta^t U(c_t),$$

where $\beta \in (0,1)$ is a subjective discount factor, and $U(\cdot)$ is an increasing and concave period utility function. The household supplies inelastically $\bar{h}$ units of labor of each variety $j \in [0,1]$. We endogenize the supply of labor in section 4.

The economy faces an exogenous natural rate of unemployment denoted u_t^n. The natural rate of unemployment reflects frictions in the labor market unrelated to nominal rigidity (Friedman, 1968). The effective supply of labor variety j, is then given by

$$h_{jt} \leq \bar{h}(1 - u_t^n). \tag{5}$$

Employment of each variety of labor is demand determined, so the household takes h_{jt} as given. Sometimes the household will not be able to sell all the units of labor it supplies. In these circumstances, it will suffer involuntary unemployment above the natural rate.

Each period $t \geq 0$, households can trade a nominally risk free discount bond denoted B_t that pays the interest rate i_t when held between periods t and $t+1$. In addition, each period the household pays real lump-sum taxes in the amount τ_t and receives profits from the ownership of firms in the amount ϕ_t. Its sequential budget constraint is then given by

$$c_t + \frac{B_t/P_t}{1+i_t} + \tau_t = \int_0^1 \frac{W_{jt}}{P_t} h_{jt} dj + \frac{B_{t-1}/P_{t-1}}{1+\pi_t} + \phi_t,$$

where

$$\pi_t \equiv \frac{P_t}{P_{t-1}} - 1 \tag{6}$$

denotes the inflation rate. The household chooses contingent plans for bond holdings and consumption to maximize its lifetime utility subject to its sequential budget constraint and some no-Ponzi game borrowing limit. The optimality conditions associated with consumption and bond holdings give rise to the Euler equation

$$U'(c_t) = \beta(1+i_t) E_t \frac{U'(c_{t+1})}{1+\pi_{t+1}}. \tag{7}$$

We now turn to a description of our proposed form of nominal rigidity, which is the novel element of the model.

2.3 Heterogeneous Downward Nominal Wage Rigidity

Each period $t \geq 0$, the nominal wage of every variety $j \in [0, 1]$ is assumed to be subject to a lower bound constraint of the form

$$W_{jt} \geq \gamma(j) W_{t-1}, \tag{8}$$

where $\gamma(j)$ is a positive and increasing function governing the degree of nominal wage rigidity of labor variety j. This formulation of downward nominal wage rigidity nests the homogeneous case studied in Schmitt-Grohé and Uribe (2016), which obtains when the function $\gamma(j)$ is independent of j. Note that the wage lower bound depends on the past aggregate wage rate, W_{t-1}, and not on the nominal wage paid on labor of type j in the previous period, W_{jt-1}. As will become clear shortly, this formulation facilitates aggregation. The function $\gamma(\cdot)$ need not be interpreted as representing a fixed ordering of labor varieties. For example, welders could be represented by $j = 0.45$ in period t and by $j = 0.73$ in $t + 1$. This could occur, for example, because welders unionized in $t+1$ or because they completed wage-bargaining negotiations with employers' representatives in that period.

We close the labor market with a slackness condition imposed at the level of each labor variety,

$$[\bar{h}(1 - u_t^n) - h_{jt}][W_{jt} - \gamma(j) W_{t-1}] = 0. \tag{9}$$

According to this condition, when an occupation suffers unemployment above the natural rate, the wage rate must be stuck at its lower bound. The slackness condition also says that if in a given occupation the wage rate is above its lower bound, then the occupation must display full employment, defined as an unemployment rate equal to the natural rate.

2.4 The Government

The central bank sets the nominal interest rate according to a Taylor rule of the form

$$1 + i_t = \frac{1 + \pi^*}{\beta} \left(\frac{1 + \pi_t}{1 + \pi^*} \right)^{\alpha_\pi} \left(\frac{y_t}{y} \right)^{\alpha_y} \mu_t, \tag{10}$$

where π^* denotes the central bank's inflation target, y_t denotes aggregate output, y denotes the steady-state value of y_t, α_π and α_y are parameters, and μ_t is an exogenous and stochastic monetary shock.

We assume that fiscal policy is passive in the sense that government solvency is satisfied independently of the path of the price level.

2.5 Equilibrium

In equilibrium, aggregate output is given by

$$y_t = z_t F(h_t). \tag{11}$$

Market clearing in the goods market requires that consumption equal output,

$$c_t = y_t. \tag{12}$$

We are now ready to define a competitive equilibrium.

Definition 1 (Competitive Equilibrium) *A competitive equilibrium is a set of processes c_t, y_t, h_t, h_{jt}, W_t, W_{jt}, P_t, π_t, and i_t satisfying* (1) *and* (3)-(12) *for all $j \in [0,1]$ and $t \geq 0$, given the initial wage W_{-1} and the exogenous disturbances z_t, μ_t, and u_t^n.*

Next, we show that the equilibrium conditions can be written in terms of a single labor variety. A by-product of this analysis is a demonstration that the model delivers a static wage Phillips curve.

2.6 Equilibrium in j^* Form

We consider an equilibrium in which for every $t \geq 0$ there exists a cut-off labor variety denoted $j_t^* \in (0,1)$ that operates at full employment, $h_{jt} = \bar{h}(1-u_t^n)$ for $j = j_t^*$, and for which the wage lower bound holds with equality, $W_{j_t^* t} = \gamma(j_t^*)W_{t-1}$. As will become clear, this equilibrium requires that the inflation target be neither too high nor too low, so as to rule out the corner solutions $j_t^* = 0$ and $j_t^* = 1$.[1] Evaluating the labor demand (3) at $j = j_t^*$, yields the condition

$$\bar{h}(1-u_t^n) = \left(\frac{\gamma(j_t^*)}{1+\pi_t^W}\right)^{-\eta} h_t, \tag{13}$$

where

$$\pi_t^W \equiv \frac{W_t}{W_{t-1}} - 1 \tag{14}$$

denotes wage inflation in period t.

Because $\gamma(j)$ is strictly increasing, it follows that all varieties $j < j_t^*$ must also pay the wage $\gamma(j_t^*)W_{t-1}$, and thus operate at full employment. To see this, let $W_t^* \equiv \gamma(j_t^*)W_{t-1}$ and suppose first, contrary to the claim, that $W_{jt} < W_t^*$ for some $j < j_t^*$. Then, by (3) we have

[1] In the vicinity of the steady state, this condition is satisfied if $1+\pi^*$ is less than $\gamma(1)$ and greater than $\left[\int_0^1 \gamma(j)^{1-\eta} dj\right]^{1/(1-\eta)}$.

that $h_{jt} = (W_{jt}/W_t)^{-\eta} h_t > (W_t^*/W_t)^{-\eta} h_t = \bar{h}(1-u_t^n)$, which violates the time constraint (5). Suppose now that, contrary to the claim, $W_{jt} > W_t^*$ for some $j < j_t^*$. Then by the same logic $h_{jt} < \bar{h}(1-u_t^n)$. Further, $W_{jt} > W_t^* = \gamma(j_t^*)W_{t-1} > \gamma(j)W_{t-1}$. So we have that in this case $\bar{h}(1-u_t^n) - h_{jt} > 0$ and $W_{jt} - \gamma(j)W_{t-1} > 0$, which violates the slackness condition (9).

It also follows that all labor varieties $j > j_t^*$ are stuck at their wage lower bound and suffer involuntary unemployment. To see this, use (3) and (8) to write, for any $j > j_t^*$, $h_{jt} = (W_{jt}/W_t)^{-\eta} h_t \leq (\gamma(j)W_{t-1}/W_t)^{-\eta} h_t < (\gamma(j_t^*)W_{t-1}/W_t)^{-\eta} h_t = \bar{h}(1-u_t^n)$. This shows that all labor varieties $j > j_t^*$ suffer involuntary unemployment above the natural rate. It then follows immediately from the slackness condition (9) that $W_{jt} = \gamma(j)W_{t-1}$, that is, wages of all labor varieties $j > j_t^*$ are stuck at their lower bounds.

Summing up, in the equilibrium we are considering, we have that

$$\begin{cases} h_{jt} = \bar{h}(1-u_t^n) \text{ and } W_{jt} = \gamma(j_t^*)W_{t-1} & \text{for } j \leq j_t^* \\ h_{jt} < \bar{h}(1-u_t^n) \text{ and } W_{jt} = \gamma(j)W_{t-1} & \text{for } j > j_t^* \end{cases}.$$

The cut-off variety j_t^* is an important object in this model because it governs the extensive margin of unemployment, that is, how many occupations will operate below potential.

Next, we analyze the determination of j_t^* in general equilibrium. To this end, write the wage aggregation equation (4) as

$$\begin{aligned} W_t^{1-\eta} &= \int_0^1 W_{jt}^{1-\eta} dj \\ &= \int_0^{j_t^*} [\gamma(j_t^*)W_{t-1}]^{1-\eta} dj + \int_{j_t^*}^1 [\gamma(j)W_{t-1}]^{1-\eta} dj \\ &= W_{t-1}^{1-\eta} \left[j_t^* \gamma(j_t^*)^{1-\eta} + \int_{j_t^*}^1 \gamma(j)^{1-\eta} dj \right]. \end{aligned}$$

Using the definition of wage inflation given in (14) and rearranging gives

$$(1+\pi_t^W)^{1-\eta} = j_t^* \gamma(j_t^*)^{1-\eta} + \int_{j_t^*}^1 \gamma(j)^{1-\eta} dj. \tag{15}$$

According to this expression, wage inflation is increasing in the cut-off labor variety j_t^*. To understand why, suppose that the cut-off variety increases from $j_t^{*'}$ to $j_t^{*''} > j_t^{*'}$. Then, all varieties from 0 to $j_t^{*'}$ are unconstrained before and after the increase in j_t^*. As a result, their wages increase from $\gamma(j_t^{*'})W_{t-1}$ to $\gamma(j_t^{*''})W_{t-1}$. Varieties j between $j_t^{*'}$ and $j_t^{*''}$ were constrained before the change and become unconstrained after. For these workers, the wage rate increases from $\gamma(j)W_{t-1} < \gamma(j_t^{*''})W_{t-1}$ to $\gamma(j_t^{*''})W_{t-1}$. Finally labor varieties $j > j_t^{*''}$ are constrained before and after the change in j_t^*, so their wages remain unchanged. It follows that the average wage increases.

We are now ready to define the competitive equilibrium in j_t^* form.

Definition 2 (Competitive Equilibrium in j^* Form) *A competitive equilibrium is a set of processes j_t^*, y_t, h_t, $w_t \equiv W_t/P_t$, i_t, π_t, and π_t^W, satisfying*

$$y_t = z_t F(h_t), \tag{16}$$

$$U'(y_t) = \beta(1+i_t)E_t \frac{U'(y_{t+1})}{1+\pi_{t+1}}, \tag{17}$$

$$z_t F'(h_t) = w_t, \tag{18}$$

$$1+i_t = \frac{1+\pi^*}{\beta}\left(\frac{1+\pi_t}{1+\pi^*}\right)^{\alpha_\pi}\left(\frac{y_t}{y}\right)^{\alpha_y}\mu_t, \tag{19}$$

$$1+\pi_t^W = \frac{w_t}{w_{t-1}}(1+\pi_t), \tag{20}$$

$$\bar{h}(1-u_t^n) = \left(\frac{\gamma(j_t^*)}{1+\pi_t^W}\right)^{-\eta} h_t, \tag{21}$$

and

$$(1+\pi_t^W)^{1-\eta} = j_t^*\gamma(j_t^*)^{1-\eta} + \int_{j_t^*}^1 \gamma(j)^{1-\eta}dj, \tag{22}$$

given the initial condition w_{-1} and the stochastic processes z_t, μ_t, and u_t^n.

Equilibrium conditions (16)–(20) are standard components of optimizing monetary models, with or without nominal rigidity. The Keynesian features of the model appear in the last two equilibrium conditions. Equation (21) says that there is one labor variety, j_t^*, for which there is full employment and the wage constraint just binds. Equation (22) says that wage inflation is a weighted average of the wage increase across varieties relative to the average wage prevailing the previous period. Taken together, these conditions leave the door open for monetary disturbances to have real effects. To see this, it suffices to consider, as an example, a situation in which the economy is initially in steady state and in period 0 experiences an unexpected purely transitory fall in the monetary disturbance μ_t. After the shock there is perfect foresight. Suppose, contrary to the claim, that the fall in μ_t does not affect the real allocation (y_t or h_t). Then, by the Euler equation (17) and the Taylor rule (19), we have that the inflation rate π_t must change either at $t=0$ or at $t=1$ or both. Also, by the labor demand (18), the real wage w_t must stay constant, otherwise h_t would move. Then, by (20), wage inflation π_t^W must change either at $t=0$ or at $t=1$ or both. In turn, by (21), j_t^* must change either at $t=0$ or at $t=1$ or both and the ratio $\gamma(j_t^*)/(1+\pi_t^W)$ must stay constant, otherwise h_t would be affected. The latter implication requires $\gamma'(j) \neq 0$. But, according to (22), the ratio $\gamma(j_t^*)/(1+\pi_t^W)$ can stay constant only if $\gamma'(j) = 0$, which is a contradiction.

3 The Wage Phillips Curve

The aggregate unemployment rate, denoted u_t, is given by the integral of the unemployment rates across all labor varieties. Formally,

$$\begin{aligned} u_t &\equiv \bar{h}^{-1} \int_0^1 (\bar{h} - h_{jt}) dj \\ &= u_t^n j_t^* + \bar{h}^{-1} \int_{j_t^*}^1 (\bar{h} - h_{jt}) dj \\ &= u_t^n j_t^* + (1 - j_t^*) - \frac{h_t}{\bar{h}} \int_{j_t^*}^1 \left(\frac{W_{jt}}{W_t} \right)^{-\eta} dj \\ &= u_t^n j_t^* + (1 - j_t^*) - \left(\frac{W_{t-1}}{W_t} \right)^{-\eta} \frac{h_t}{\bar{h}} \int_{j_t^*}^1 \gamma(j)^{-\eta} dj. \end{aligned}$$

Using the definition of wage inflation given in (14) and equilibrium condition (21) to eliminate $(W_{t-1}/W_t)^{-\eta} h_t$, we can write

$$u_t = u_t^n + (1 - u_t^n) \left[(1 - j_t^*) - \int_{j_t^*}^1 \left(\frac{\gamma(j)}{\gamma(j_t^*)} \right)^{-\eta} dj \right]. \tag{23}$$

The right hand side of equation (23) is decreasing in j_t^*. It follows that as j_t^* increases, the unemployment rate falls. This is intuitive because all activities below the cut-off threshold j_t^* operate at full employment, so the higher the cut-off threshold is, the smaller the set of activities displaying involuntary unemployment above the natural rate will be.

Given the natural rate of unemployment, u_t^n, equations (22) and (23) implicitly represent a contemporaneous relationship involving only unemployment and wage inflation (u_t and π_t^W). Further, u_t and π_t^W are negatively related. To see this, recall that equation (22) implies that an increase in wage inflation allows for a larger set of labor varieties to be unconstrained by the wage lower bound (i.e., an increase in wage inflation raises the cut-off variety j_t^*). In turn, equation (23) says that the larger the set of unconstrained labor varieties is, the lower unemployment will be. Thus, the model's implied relationship between unemployment and wage inflation represents a downward sloping wage Phillips curve. This relationship captures the idea, often used in the early empirical literature on downward nominal wage rigidity, that inflation greases the wheels of the labor market (e.g., Card and Hyslop, 1997).[2]

We note that the wage Phillips curve implied by the model is static. In particular, it does not feature future expected inflation. In this sense, the present model departs from the new-Keynesian framework in which the wage Phillips curve is forward looking (Erceg, Henderson, and Levin, 2000; Galí, 2011) and can be interpreted as providing microfoundations to Phillips's original formulation of a static wage Phillips curve (Phillips, 1958). The following proposition summarizers this result.

Proposition 1 (Phillips's Phillips Curve) *The model with heterogeneous downward nominal wage rigidity implies a static negative relation between wage inflation, π_t^W, and the unemployment rate, u_t.*

We now turn to the characterization of the wage Phillips curve in the short and long runs.

3.1 The Short-Run Wage Phillips Curve

The short-run wage Phillips curve is the locus of points (u_t, π_t^W) satisfying equations (22) and (23) for a given value of the natural rate of unemployment u_t^n.

To illustrate the properties of the short-run wage Phillips curve implied by the model, we consider a linear functional form for $\gamma(j)$ and calibrate its parameters. Specifically, assume that

$$\gamma(j) = (1 + \pi^*)^\delta (\Gamma_0 + \Gamma_1 j). \tag{24}$$

Here, the parameter $\delta \in [0, 1]$ captures the degree of wage indexation to long-run inflation, and the parameters $\Gamma_0, \Gamma_1 > 0$ govern the degree of downward nominal wage rigidity. The time unit is a quarter. We set $\Gamma_0 = 0.978$ and $\Gamma_1 = 0.031$ to match the slope of the wage Phillips curve at a particular wage-inflation unemployment pair. Specifically, we target a slope of -0.74/4, which is consistent with the estimate presented in Galí and Gambetti (2019) for the United States over the period 1986 to 2007. Also, we target a steady-state rate of unemployment of 6 percent and a steady-state rate of inflation of 3 percent per year to match the average values observed in the United States over the period 1986 to 2007 (the sample period in Galí and Gambetti, 2019). That is, we assume that when π_t^W is equal to 3 percent per year, then u_t is equal to 6 percent and the slope of the wage Phillips curve is -0.74. We set the steady-state natural rate of unemployment at 4 percent ($u^n = 0.04$) and fix u_t^n at u^n. We assume full indexation of wages ($\delta = 1$), as in much of the related literature. For example, Christiano, Eichenbaum, and Evans (2005) and Smets and Wouters (2007) assume

[2] The phrase "inflation greases the wheels of the labor market" is often attributed to Tobin (1972), although that paper does not explicitly use it.

Table 1: Parameter Values

Parameter	Value	Description
Γ_0	0.978	Parameter of the $\gamma(j)$ function
Γ_1	0.031	Parameter of the $\gamma(j)$ function
δ	1	Wage indexation parameter of the $\gamma(j)$ function
π^*	$1.03^{1/4} - 1$	Steady state inflation rate
u^n	0.04	Natural rate of unemployment
η	11	Elasticity of substitution across labor varieties
β	0.99	Subjective discount factor
σ	1	Inverse of intertemporal elasticity of substitution
θ	5	Inverse of Frisch elasticity of labor supply
α	0.75	Labor elasticity of output
α_π	1.5	Inflation coefficient of Taylor rule
α_y	0.125	Output coefficient of Taylor rule
ρ_μ	0.5	Persistence of monetary shock
ρ_z	0.9	Persistence of technology shock

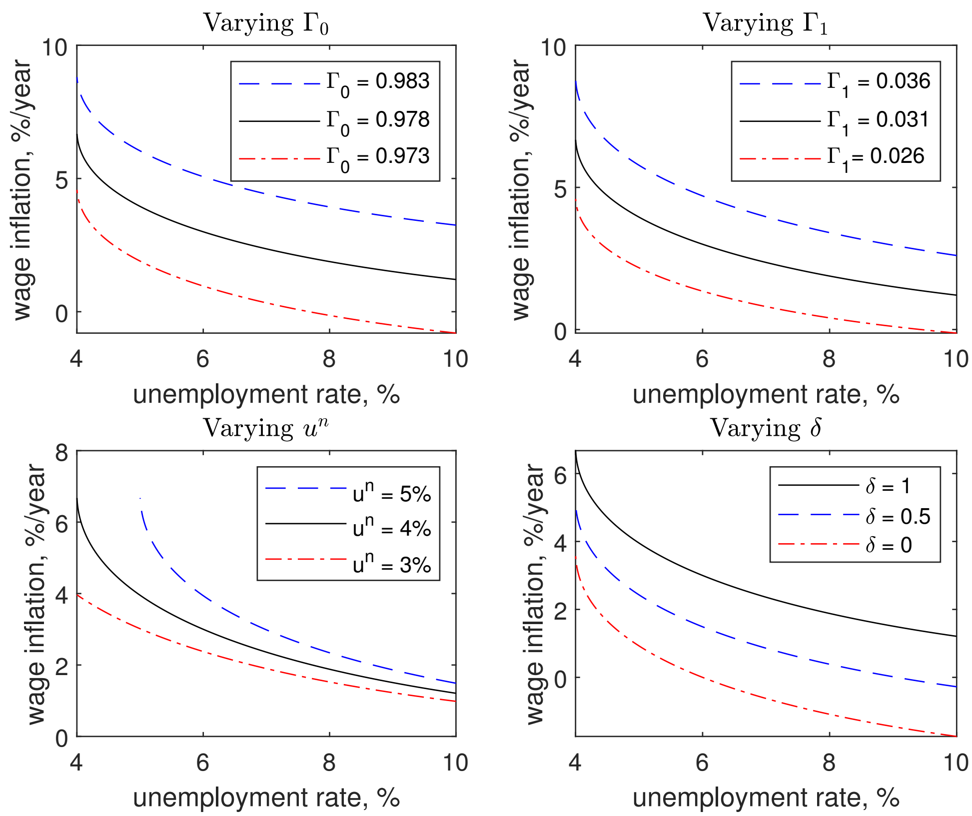
Note. The time unit is a quarter.

that the weights on steady-state inflation and lagged inflation in the indexation scheme add up to one. Section 3.2 shows that when $\delta = 1$, the steady-state real allocation (y_t, h_t, and u_t) is independent of the inflation rate. Finally, we set the elasticity of substitution across labor varieties to 11 ($\eta = 11$). This number is an average of the values used in Erceg, Henderson, and Levin (2000), Christiano, Eichenbaum, and Evans (2005), and Galí (2015). The top panel of Table 1 summarizes the parameter values used in the computation of the Phillips curve. (The bottom panel of this table is discussed in section 4.)

Figure 1 displays the implied short-run wage Phillips curve in the space (u_t, π_t^W) for the baseline calibration of the model and several variations thereof. The Phillips curve associated with the baseline calibration is shown with a solid line. By construction, when the unemployment rate is 6 percent, the annual wage inflation rate is 3 percent. Also by construction, at that point, the slope of the Phillips curve is equal to -0.74. A drop in wage inflation from 3 to 2 percent per year is associated in the short run with an increase in the unemployment rate from 6 to 7.5 percent.

Figure 1 also shows that a given level of unemployment requires a higher wage inflation rate the more downwardly rigid nominal wages are (the higher Γ_0 and Γ_1 are) and the higher the degree of wage indexation is (the higher δ is). That is, an increase in any of these three parameters shifts the short-run Phillips curve up and to the right. The intuition behind these effects is as follows. Wage inflation acts as a lubricant of the labor market because the

Figure 1: The Short-Run Wage Phillips Curve



Notes. Solid lines correspond to the baseline calibration. The parameters Γ_0, Γ_1, and δ pertain to the wage lower bound function $\gamma(j) = (1 + \pi^*)^\delta(\Gamma_0 + \Gamma_1 j)$ (equation 24). The parameter u^n represents the natural rate of unemployment. The figure shows that the short-run wage Phillips curve shifts up and to the right when the degree of downward nominal wage stickiness increases (Γ_0 or Γ_1 increase), when the natural rate of unemployment rises (u^n increases), or when the degree of wage indexation increases (δ increases).

higher wage inflation is, the larger the number of activities that are not constrained by the wage lower bound will be. An increase in Γ_0, Γ_1, or δ raises the wage lower bound. Thus, the economy needs more lubricant to maintain the same level of unemployment. (For the same reason, an increase in the inflation target π^* (not shown in Figure 1) moves the Phillips curve up and to the right.) Finally, an increase in the natural rate of unemployment shifts the short-run Phillips curve to the right, so that at every level of wage inflation the economy suffers more unemployment.

3.2 The Long-Run Wage Phillips Curve

The long-run wage Phillips curve is the locus of points $(u_t, \pi_t^W) = (u, \pi^W)$ satisfying equations (22) and (23) for $u_t^n = u^n$, where variables without a time subscript denote steady-state values. The difference between the short- and long-run Phillips curves is that in the long run wage inflation and price inflation are both equal to the inflation target. Specifically, because output is constant in the steady state, the Euler equation (17) implies the long-run Fisher relationship

$$i = \frac{1+\pi}{\beta} - 1.$$

This expression and the Taylor rule (19) imply that in the steady state inflation must be at its target level,

$$\pi = \pi^*.$$

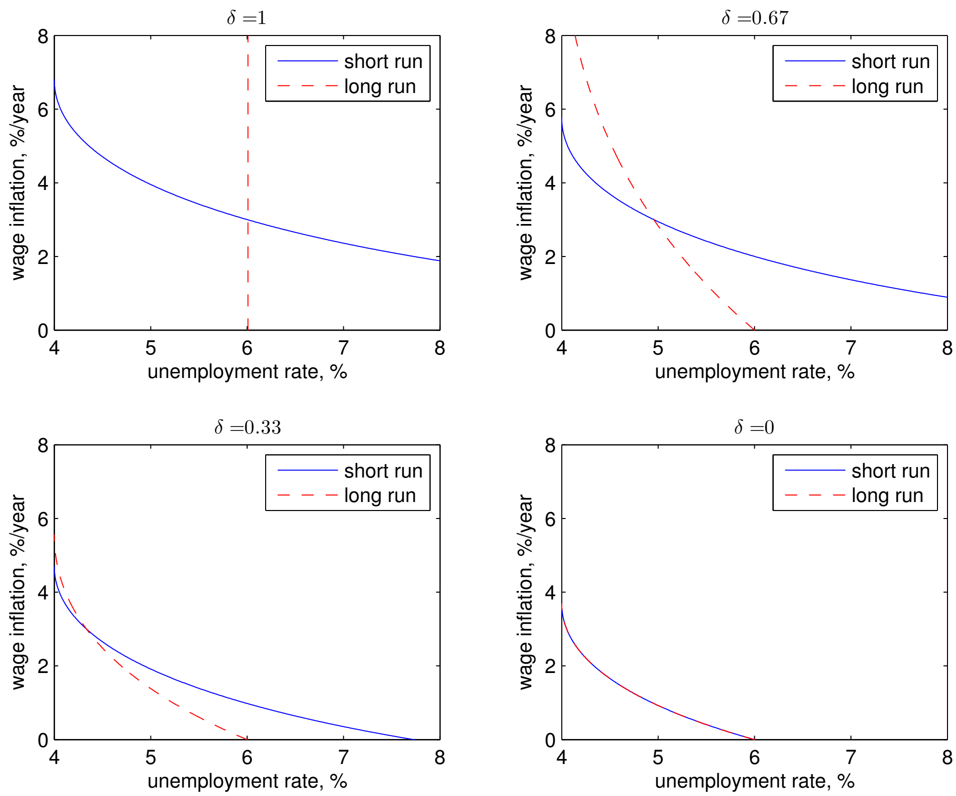
Since in the steady state the real wage is constant, equilibrium condition (20) implies that wage inflation equals product-price inflation,

$$\pi^W = \pi^*.$$

Equilibrium conditions (22) and (23) evaluated at $u_t = u$, $\pi_t^W = \pi^*$, and $u_t^n = u^n$ constitute a relationship between inflation and unemployment in the steady state, which we call the long-run wage Phillips curve. It follows immediately that in the absence of wage indexation, that is, when the function $\gamma(\cdot)$ is independent of π^*, the short- and long-run Phillips curves coincide. But this ceases to be the case when wages are indexed to steady-state inflation. To see this, consider again the linear functional form for $\gamma(\cdot)$ given in equation (24). In this case, equilibrium conditions (22) and (23) evaluated at $u_t = u$, $\pi_t^W = \pi^*$, and $u_t^n = u^n$, become

$$(1+\pi^W)^{(1-\eta)(1-\delta)} = j^*\widetilde{\gamma}(j^*)^{1-\eta} + \int_{j^*}^{1} \widetilde{\gamma}(j)^{1-\eta} dj, \tag{25}$$

Figure 2: The Long-Run Wage Phillips Curve



Notes. The parameter δ pertains to the wage lower bound function $\gamma(j) = (1+\pi^*)^\delta(\Gamma_0 + \Gamma_1 j)$ (equation 24). The figure shows that the long-run wage Phillips curve is in general downward sloping and steeper than its short-run counterpart. The long-run wage Phillips curve is vertical when $\delta = 1$ and identical to the short-run wage Phillips curve when $\delta = 0$.

$$u = u^n + (1-u^n)\left[(1-j^*) - \int_{j^*}^{1}\left(\frac{\widetilde{\gamma}(j)}{\widetilde{\gamma}(j^*)}\right)^{-\eta} dj\right], \tag{26}$$

where $\widetilde{\gamma}(j) \equiv \Gamma_0 + \Gamma_1 j$.

It is clear from (25) and (26) that under full wage indexation ($\delta = 1$) the long-run wage Phillips curve is perfectly vertical in the space (u, π^W). This is intuitive. Under full indexation, an increase in inflation fails to inject grease in the labor market in the long run, as indexation soaks it up one for one. By contrast, under imperfect indexation ($\delta < 1$), only a fraction δ of an increase in inflation is absorbed by indexation and the rest is grease to the labor market.

To see more precisely what happens for intermediate degrees of wage indexation ($\delta \in (0,1)$), Figure 2 displays the long-run wage Phillips curve for four different degrees of wage indexation and compares it to its short-run counterpart. The figure illustrates that absent full indexation the long-run wage Phillips curve is downward sloping and that as the degree of wage indexation goes down the slope of the long-run wage Phillips curve falls. In fact, the long-run wage Phillips curve rotates around the point $(u, \pi^W) = (0.06, 0)$ counterclockwise as δ declines. To see why this is so, recall that the calibration targets an unemployment rate of 6 percent and assumes full indexation. Therefore, the left-hand side of (25) is equal to 1, regardless of the value of π^W. This uniquely pins down the steady value of j^* and by equation (26) also the steady state value of u. When $\delta < 1$ and inflation is zero ($\pi^W = 0$), then the left-hand side of equation (25) is also equal to 1, regardless of the value of δ. Thus, the long-run wage Phillips curve must contain the point $(u, \pi^W) = (0.06, 0)$ for any value of δ.

Comparing the long-run and the short-run Phillips curves, the figure shows that for positive degrees of wage indexation $\delta \in (0, 1]$, the long-run Phillips curve is steeper than its short-run counterpart. The intuition why the wage Phillips curve is steeper in the long run is as follows. In the short run, movements in the inflation rate are not accompanied by movements in the long-run rate of inflation, so they grease the labor market one for one. By contrast, to the extent that δ is greater than zero, only a fraction $(1 - \delta)$ of an increase in inflation greases the labor market in the long run.

4 How Important Is the Forward-Looking Component of the Wage Phillips Curve?

This section characterizes the equilibrium dynamics of the heterogeneous downward nominal wage rigidity (HDNWR) model and compares them to those implied by the new-Keynesian (NK) model of wage stickiness. Because an endogenous labor supply is a necessary feature of the latter model, to facilitate comparison, the section begins by endogenizing the labor choice in the former model.

4.1 The HDNWR Model with Endogenous Labor Supply

Suppose now that the representative household derives disutility from supplying labor. Specifically, replace the lifetime utility function considered thus far with the function

$$E_0 \sum_{t=0}^{\infty} \beta^t \left[U(c_t) - \int_0^1 V(h_{jt}^s) dj \right], \tag{27}$$

where h^s_{jt} denotes the amount of labor of type j supplied in period t, and $V(\cdot)$ is a convex labor disutility function. To facilitate aggregation, we use the functional form

$$V(h) = \frac{h^{1+\theta}}{1+\theta}, \tag{28}$$

which is often used in business-cycle analysis (e.g., Galí, 2015). As before, there is rationing in the labor market: for each labor type j, at the going wage W_{jt} households may not be able to sell all the units of labor they offer. The household sets its desired supply of labor of variety j to equate the marginal rate of substitution between labor and consumption to the variety-specific real wage. Formally, the supply of labor of type j is given by

$$\frac{V'(h^s_{jt})}{U'(c_t)} = w_{jt}, \tag{29}$$

where $w_{jt} \equiv W_{jt}/P_t$. We continue to assume that there is an exogenous amount of involuntary unemployment unrelated to wage stickiness, embodied in the variable u^n_t denoting the natural rate of unemployment. The restriction that employment is voluntary now takes the form

$$h_{jt} \leq h^s_{jt}(1-u^n_t). \tag{30}$$

This expression says that the household is not willing to have more members employed than the ones it voluntarily supplies to the market net of the ones that are naturally unemployed.

The household's budget constraint and the optimality conditions associated with consumption and bond holdings are unchanged. The firm's demand for labor of variety $j \in [0,1]$, given by equation (3) is also unchanged.

As before, we consider an equilibrium in which each period $t \geq 0$ there is a cut-off labor variety, j^*_t, that operates at full employment,

$$h_{j^*_t t} = h^s_{j^*_t t}(1-u^n_t), \tag{31}$$

and for which the wage constraint holds with equality,

$$W_{j^*_t t} = \gamma(j^*_t) W_{t-1}. \tag{32}$$

Combining these two conditions with the labor demand (3) and the labor supply (29) yields

$$\frac{V'\left(\frac{h_t}{1-u^n_t}\left(\frac{\gamma(j^*_t)}{1+\pi^W_t}\right)^{-\eta}\right)}{U'(c_t)} = \frac{\gamma(j^*_t) w_{t-1}}{1+\pi_t}. \tag{33}$$

It can be shown that, as in the case of an inelastic labor supply, all labor varieties $j < j_t^*$ operate at full employment and are paid the same wage as variety j_t^*. Also, all varieties $j > j_t^*$ are constrained by the wage lower bound and suffer unemployment above the natural rate.

The definition of a competitive equilibrium with an endogenous labor supply is then identical to that given in Definition 2, except that equation (21) is replaced by equation (33).

With an endogenous labor supply, the unemployment rate is the ratio of unemployed labor to the total labor supply. Formally,

$$u_t = \frac{\int_0^1 (h_{jt}^s - h_{jt}) dj}{\int_0^1 h_{jt}^s dj}.$$

Using the functional form (28) for the disutility of labor and equations (3), (29), (31), and (32), we can rewrite the unemployment rate as

$$u_t = u_t^n + (1 - u_t^n) \frac{\int_{j_t^*}^1 \left[\left(\frac{\gamma(j)}{\gamma(j_t^*)} \right)^{\frac{1}{\theta}} - \left(\frac{\gamma(j)}{\gamma(j_t^*)} \right)^{-\eta} \right] dj}{j_t^* + \int_{j_t^*}^1 \left(\frac{\gamma(j)}{\gamma(j_t^*)} \right)^{\frac{1}{\theta}} dj}. \tag{34}$$

Note that as the elasticity of labor supply approaches zero ($\theta \to \infty$), equations (33) and (34) converge to equations (21) and (23), and the model becomes the one with inelastic labor supply studied in sections 2 and 3.

The following definition summarizes the equilibrium with endogenous labor supply.

Definition 3 (Competitive Equilibrium with Endogenous Labor Supply) *A competitive equilibrium in the economy with endogenous labor supply is a set of processes j_t^*, y_t, h_t, u_t, w_t, i_t, π_t, and π_t^W, satisfying* (16)-(20), (22), (33), *and* (34), *given the initial condition w_{-1} and the stochastic processes z_t, μ_t, and u_t^n.*

As in the case of an inelastic labor supply, the model features a static wage Phillips curve implicitly given by equations (22) and (34).

In spite of the fact that the model features occasionally binding constraints at the level of individual varieties of labor, the complete set of equilibrium conditions given in Definition 3 does not. This means that the model is amenable to a characterization of the equilibrium dynamics using perturbation methods. We summarize this result in the following proposition:

Proposition 2 (HDNWR and Perturbation) *The equilibrium dynamics of the HDNWR model with inelastic or elastic labor supply described in Definitions 2 and 3, respectively, can be approximated using perturbation techniques.*

Thus, to obtain the implied impulse responses of the model to exogenous shocks we can follow the customary approach of linearizing the equilibrium conditions around the nonstochastic steady state.

The quantitative analysis that follows adopts this approach. The calibration of the model is summarized in Table 1. The parameters appearing in the top panel of the table were already discussed in section 3. Because the model now features an endogenous labor supply, the parameters Γ_0 and Γ_1 were recalibrated using the same targets for the slope of the Phillips curve and steady-state unemployment. The implied values are $\Gamma_0 = 0.9781$ and $\Gamma_1 = 0.0310$, which are the same as those associated with the HDNWR model with inelastic labor supply up to the third significant digit.

We assume a period consumption subutility function of the form $U(c) = (c^{1-\sigma} - 1)/(1-\sigma)$ and a production function of the form $F(h) = h^{\alpha}$. Following Galí (2015), we set $\sigma = 1$ $\alpha = 0.75$, $\beta = 0.99$, $\theta = 5$, $\alpha_{\pi} = 1.5$, and $\alpha_y = 0.5/4$.

4.2 Response to a Monetary Shock

We assume that the monetary shock follows an autoregressive process of order one

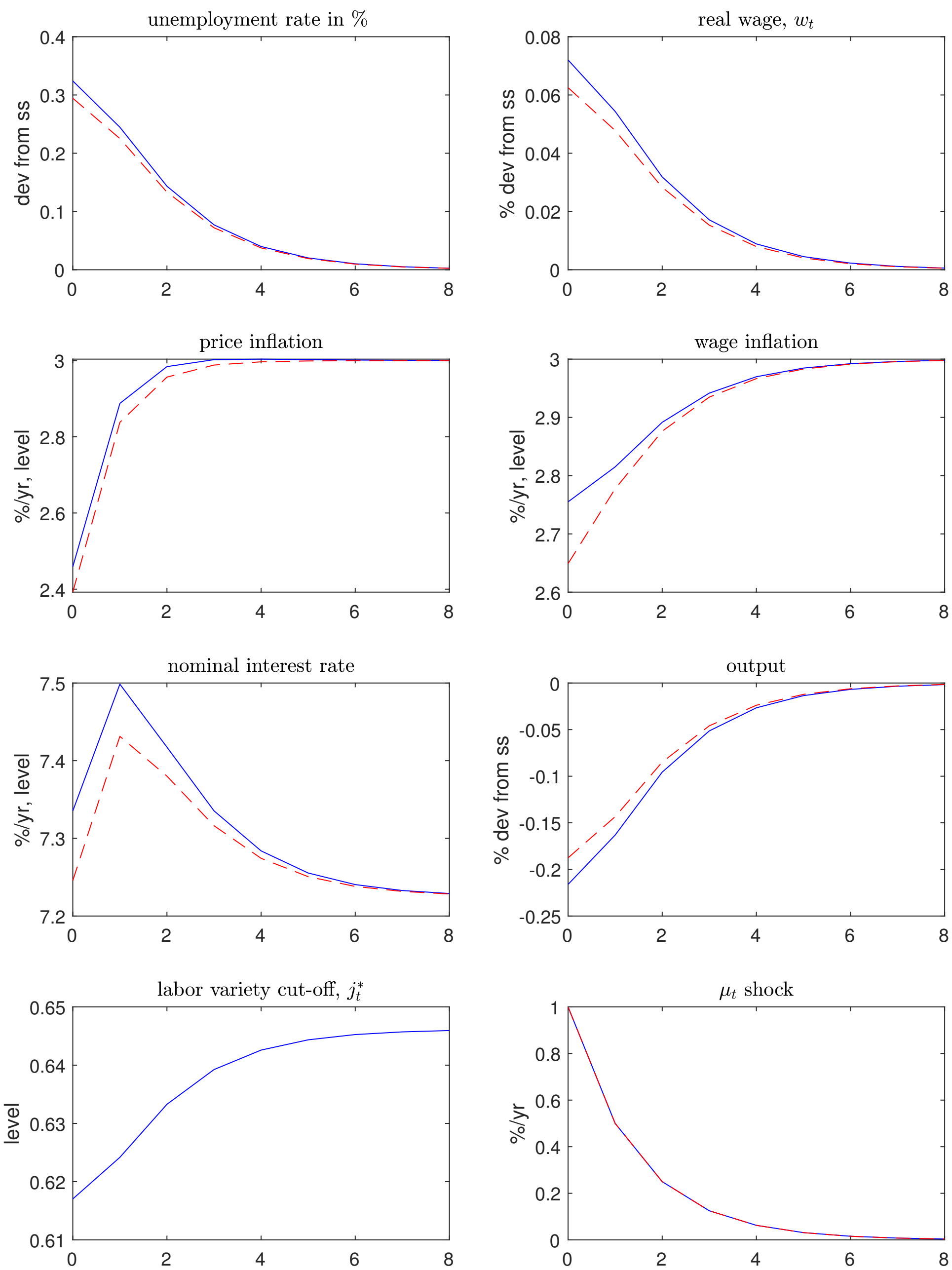
$$\ln \mu_t = \rho_\mu \ln \mu_{t-1} + \epsilon_t^\mu, \tag{35}$$

where ϵ_t^μ is a mean zero i.i.d. innovation, and $\rho_\mu \in [0, 1)$ is a parameter. Following Galí (2015), we set $\rho_\mu = 0.5$.

Figure 3 displays with solid lines the impulse response to a one percent annualized increase in μ_t. In equilibrium this monetary contraction results in a 0.11 percentage point increase in the policy interest rate. The increase in the interest rate is smaller than the increase in μ_t because of the contemporaneous adjustment of the endogenous variables that enter the Taylor rule, π_t and y_t. The model predicts that the tightening in monetary conditions is deflationary. An efficient adjustment of the labor market would require a fall in nominal wages large enough to perfectly offset the fall in prices. However, due to the presence of downward nominal wage rigidity, the decline in nominal wages is insufficient. That is, a larger number of job varieties become constrained by the lower bound on nominal wages. This frictional adjustment is reflected in a decline in the labor variety cutoff j_t^*. In turn, the fact that the real wage is inefficiently high for more labor varieties causes an increase in involuntary unemployment and hence a decline in output and consumption.

A key difference between the present model and the NK sticky wage model is that the Phillips curve implied by the former is static whereas the one implied by the latter is forward-looking. Here, we wish to ascertain whether this difference is relevant for the predicted

Figure 3: Impulse Responses to a Monetary Tightening



Notes. Solid lines correspond to the HDNWR model and dashed lines to the NK model with Calvo wage stickiness. The size of the monetary shock is 1 percent per annum and its serial correlation is 0.5. The horizontal axes measure quarters after the shock.

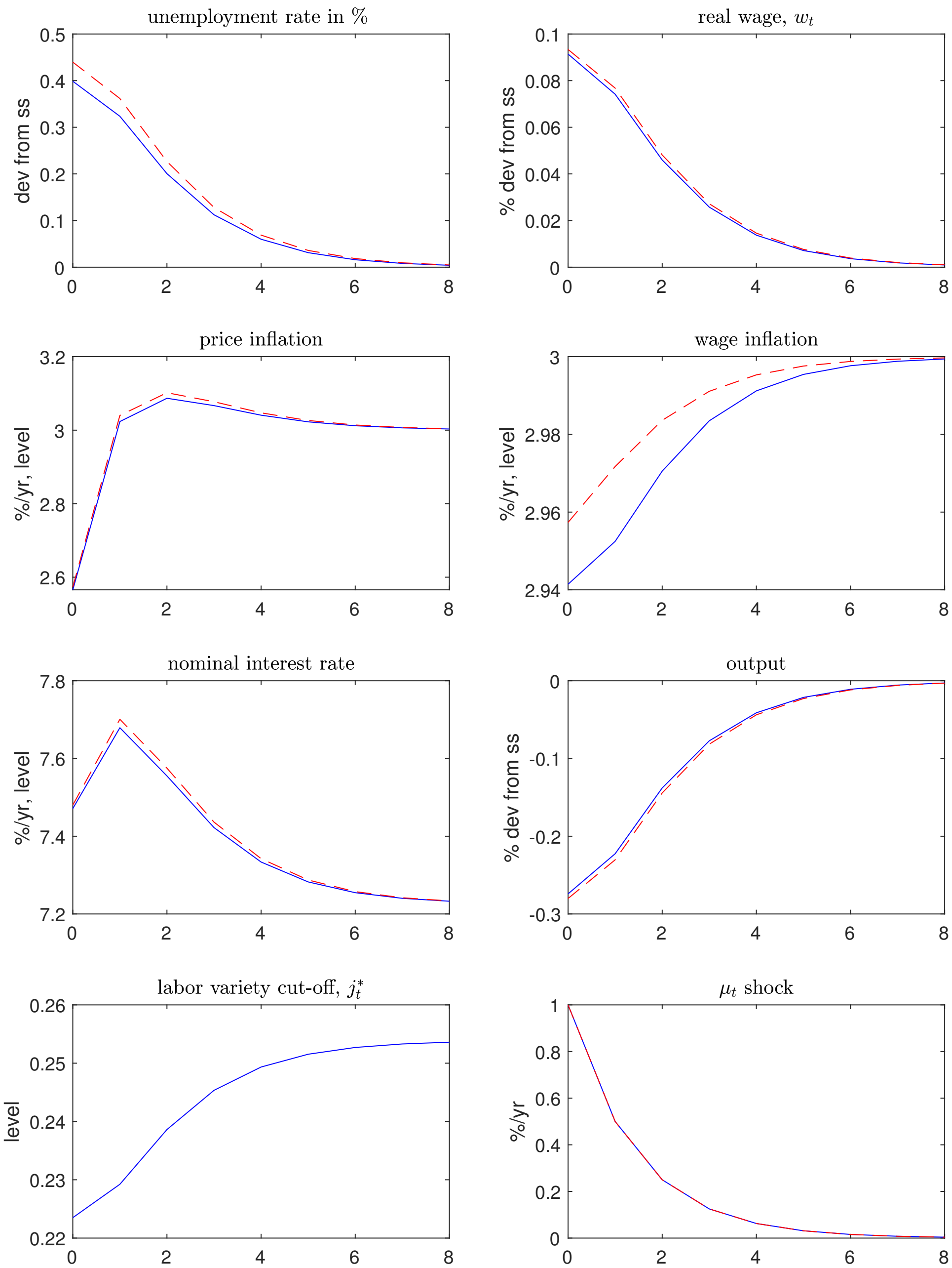
equilibrium dynamics. To this end, we consider a canonical NK sticky-wage model that departs from the current model only in its wage setting module. Specifically, we assume that wages are set in a Calvo-Yun fashion as in Erceg, Henderson, and Levin (2000) and define the unemployment rate as in Galí (2011) and Casares (2010). A detailed derivation of the NK model we use here can be found in a technical appendix (Schmitt-Grohé and Uribe, 2022). All parameters of the NK model that are common to the present model are assigned the same values, namely, those given in Table 1. The common parameters are π^*, η, β, σ, θ, α, α_π, α_y, and ρ_μ. As in the HDNWR model, we assume full indexation of wages to steady-state inflation.

It remains to explain how we calibrate the degree of nominal wage rigidity in the NK model. We cannot directly adopt the strategy used to calibrate the HDNWRA model, namely, to match the slope of the implied wage Phillips curve to the one estimated by Galí and Gambetti (2019). The reason is that the empirical Phillips curve estimated by Galí and Gambetti is not forward looking and therefore does not have a natural theoretical counterpart in the NK model. Instead, we assume that the fraction of types of labor that cannot reoptimize wages in any given period in the NK model is equal to the steady-state fraction of types of labor that are stuck at the wage lower bound in the HDNWR model. Formally, letting θ_w denote the fraction of wages that are not set optimally in any given period in the NK model, we impose $\theta_w = 1 - j^*$, where j^* is the deterministic steady-state value of j_t^*. The resulting value of θ_w is 0.35. This value is low relative to those typically used in the NK literature, which come to a large extent from full information DSGE estimation of NK models with forward-looking wage Phillips curves. For example, Galí (2015) sets θ_w to 0.75. To address this issue, we also consider a calibration in which $\theta_w = 1 - j^* = 0.75$.

Figure 3 displays with dashed lines the response of the NK model to a 1 percent per annum increase in the monetary shock μ_t. The figure shows that for most variables the response of the NK and HDNWR models are quite close. This result is robust to using the more conventional higher degree of wage rigidity. Following Galí (2015), we increase θ_w from 0.35 to 0.75. To preserve comparatiliby, we recalibrate the HDNWR model. Specifally, we drop the requirement that it matches the slope of the Galí-Gambetti wage Phillips curve and instead target a value of 0.75 for $1 - j^*$. The resulting values of Γ_0 and Γ_1 are 0.9908 and 0.0175. Figure 4 displays the predicted impulse responses. Understandably, both models predict a more subdued response of wage inflation and a larger response of unemployment. The important point for the purpose of the present discussion, however, is that both models deliver quite similar dynamics.

The implication of this result is that the forward-looking nature of the wage Phillips curve in the NK framework does not appear to play a crucial role for equilibrium dynamics,

Figure 4: Impulse Responses to a Monetary Tightening with a Higher Degree of Wage Rigidity ($\theta_w = 1 - j^* = 0.75$)



Notes. Solid lines correspond to the HDNWR model and dashed lines to the NK model with Calvo wage stickiness. The size of the monetary shock is 1 percent per annum and its serial correlation is 0.5. The horizontal axes measure quarters after the shock.

at least for the calibrations considered here.

4.3 Response to a Technology Shock

Figure 5 displays the response of the HDNWR model to a 1-percent positive productivity shock (a 1 percent innovation in z_t). The shock is assumed to follow a first-order autoregressive process of the form

$$\ln z_t = \rho_z \ln z_{t-1} + \epsilon_t^z,$$

where ϵ_t^z is a mean-zero i.i.d. disturbance and ρ_z is a parameter. Following Galí (2015), we set ρ_z equal to 0.9.

The increase in output following the positive technology shock puts downward pressure on product-price inflation. The increase in labor productivity following the technological improvement pushes nominal wages up. This relaxes the wage constraint for some wage varieties (j_t^* goes up on impact), inducing a fall in unemployment in the initial period. As the technology shock begins to return to its stationary position, real wages fall. However, due to the presence of wage rigidity, they fall at a slower pace than the one consistent with full employment. As a result, unemployment rises and remains above steady state throughout the transition.

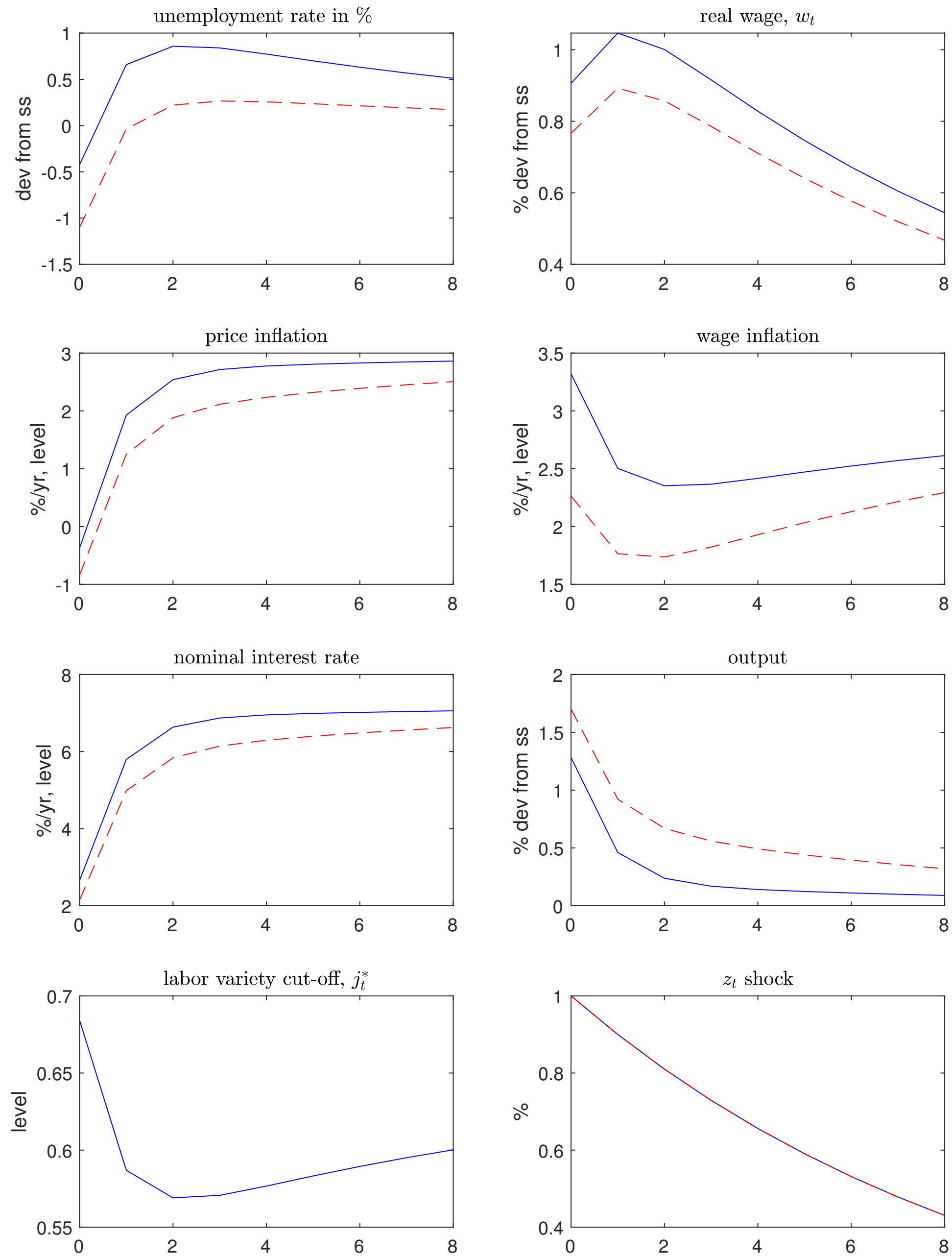
The response of the NK model to the positive productivity shock, shown with dashed lines in Figure 5, is similar. The main difference is that under the present calibration in the NK model unemployment experiences a larger decline on impact and a smaller subsequent increase. This difference in the response of unemployment is due to the relatively low value picked for the degree of wage rigidity ($\theta_w = 0.35$). When we set θ_w to the more conventional value of 0.75 and recalibrate the HDNWR model accordingly, then the response of unemployment to the technological improvement is almost the same in both models. This result is shown in Figure 6. The two models produce virtually the same responses to the positive productivity shock not only for unemployment but also for most of the other endogenous variables displayed in the figure.

Overall, the results of the present section indicate that the forward looking component in the NK wage Phillips curve does not play a central role in shaping the impulse responses to monetary and productivity shocks.

5 Conclusion

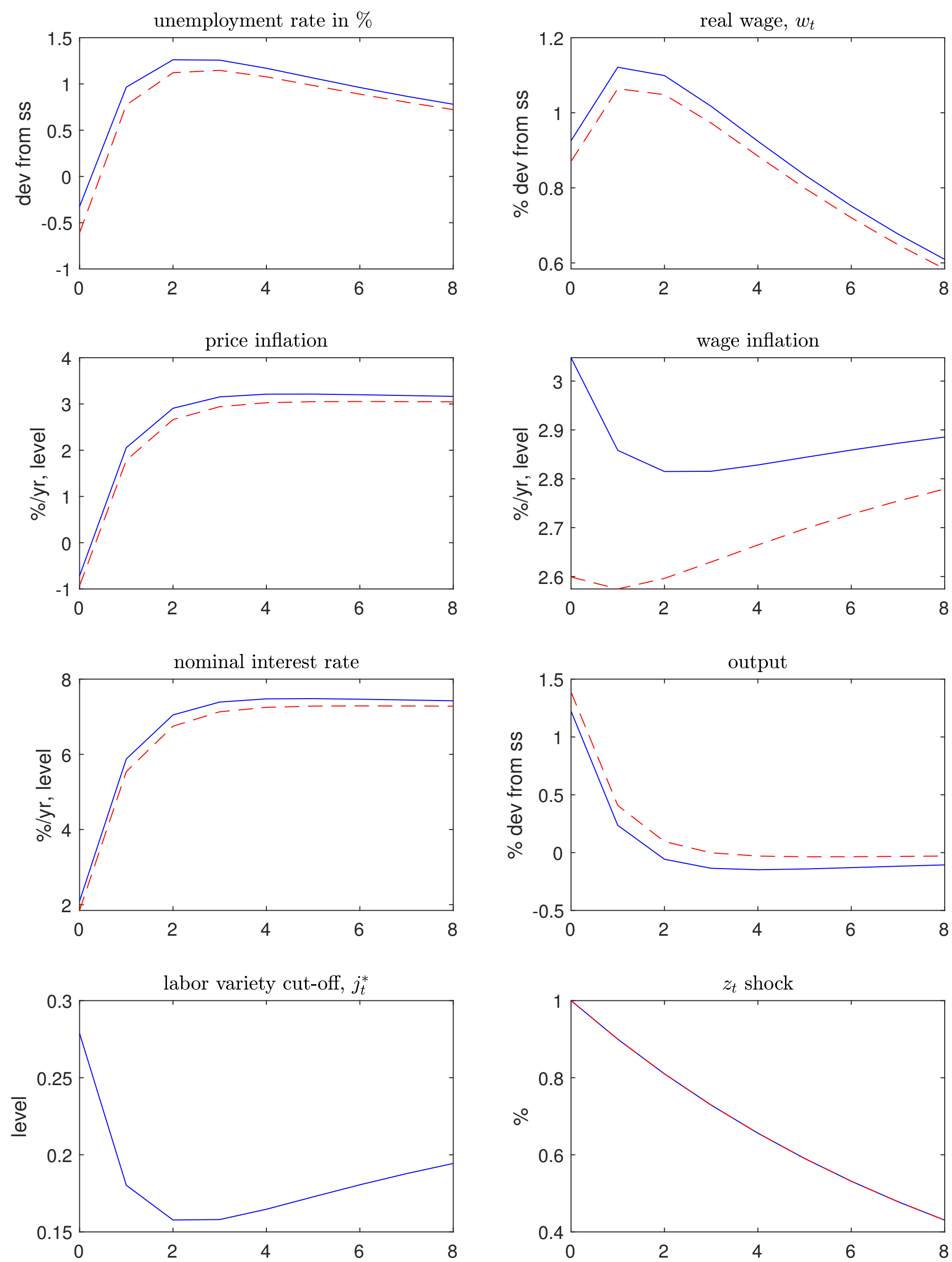
A distinctive feature of the NK model is a forward-looking Phillips curve. Yet, it is not clear what role this feature plays in shaping macroeconomic dynamics. This paper makes a step

Figure 5: Impulse Responses to a Productivity Shock



Notes. Solid lines correspond to the HDNWR model and dashed lines to the NK model with Calvo wage stickiness. The size of the shock is 1 percent and its serial correlation is 0.9.

Figure 6: Impulse Responses to a Productivity Shock with a Higher Degree of Wage Rigidity ($\theta_w = 1 - j^* = 0.75$)



Notes. Solid lines correspond to the HDNWR model and dashed lines to the NK model with Calvo wage stickiness. The size of the shock is 1 percent and its serial correlation is 0.9.

toward putting the forward-looking nature of the NK Phillips curve into perspective.

It first establishes that the forward-looking component of the Phillips curve is not a necessary characteristic of optimizing models with nominal rigidity and forward-looking agents. It does so by building a model with heterogeneous downward nominal wage rigidity that nests as a special case the standard (homogeneous) downward nominal wage rigidity framework. The model with heterogeneous downward nominal wage rigidity delivers a static wage Phillips curve and is amenable to analysis using perturbation methods.

Under standard calibrations, the proposed model delivers equilibrium dynamics in response to monetary and technology shocks that are qualitatively and quantitatively similar to those implied by the NK model of wage stickiness. This result suggests that a forward-looking component in the wage Phillips curve does not necessarily play a critical role for the predicted dynamic behavior of key macroeconomic indicators.

References

Barattieri, Alessandro, Susanto Basu, and Peter Gottschalk, “Some Evidence on the Importance of Sticky Wages,” *American Economic Journal: Macroeconomics 6,* January 2014, 70-101.

Benigno, Pierpaolo, and Luca Antonio Ricci, “The Inflation-Output Trade-Off with Downward Wage Rigidities,” *American Economic Review 101,* June 2011, 1436-1466.

Casares, Miguel, “Unemployment as Excess Supply of Labor: Implications for Wage and Price Inflation,” *Journal of Monetary Economics 57,* 2010, 233-243.

Christiano, Lawrence J., Martin Eichenbaum, and Charles L. Evans, “Nominal Rigidities and the Dynamic Effects of a Shock to Monetary Policy,” *Journal of Political Economy 113,* February, 2005, 1–45.

Card, David, and Dean Hyslop, “Does Inflation ‘Grease the Wheels of the Labor Market’?,” in Christina D. Romer and David H. Romer, Editors, *Reducing Inflation: Motivation and Strategy,* University of Chicago Press, January 1997, 71–122.

Dupraz, Stéphane, Emi Nakamura, and Jón Steinsson, “A Plucking Model of Business Cycles,” working paper, August 6, 2022.

Erceg, Christopher J., Henderson, Dale W., and Levin, Andrew T., “Optimal Monetary Policy With Staggered Wage and Price Contracts,” *Journal of Monetary Economics 46,* October 2000, 281–313.

Faia, Ester, “Optimal Monetary Policy Rules with Labour Market Frictions,” *Journal of Economic Dynamics and Control 32,* May 2008, 1357-1720.

Friedman, Milton, “The Role of Monetary Policy,” *American Economic Review 58,* March 1968, 1-17.

Galí, Jordi, “The Return of the Wage Phillips Curve,” *Journal of the European Economic Association 9,* June 2011, 436–461.

Galí, Jordi, *Monetary Policy, Inflation, and the Business Cycle,* Princeton University Press: Princeton, NJ, 2015.

Galí, Jordi, and Luca Gambetti, “Has the U.S. Wage Phillips Curve Flattened? A Semi-Structural Exploration,” NBER Working Paper No. 25476, January 2019.

Gertler, Mark, Luca Sala, and Antonella Trigari, “An Estimated Monetary DSGE Model with Unemployment and Staggered Nominal Wage Bargaining,” *Journal of Money, Credit and Banking 40,* December 2008, 1713-64.

Gottschalk, Peter, “Downward Nominal-Wage Flexibility: Real or Measurement Error?,” *The Review of Economic and Statistics 87,* August 2005, 556-568.

Jo, Yoon Joo, “Establishing downward nominal wage rigidity through cyclical changes in the wage distribution," Texas A&M University, September 23, 2022.

Kahn, Shulamit, "Evidence of Nominal Wage Stickiness from Microdata," *American Economic Review 87,* 1997, 993-1008.

Phillips, A. William, "The Relation Between Unemployment and the Rate of Change of Money Wage Rates in the United Kingdom, 1861–1957," *Economica 25,* November 1958, 283–299.

Schmitt-Grohé, Stephanie, and Martín Uribe, "Downward Nominal Wage Rigidity, Currency Pegs, And Involuntary Unemployment," *Journal of Political Economy 124,* October 2016, 1466–1514.

Schmitt-Grohé, Stephanie, and Martín Uribe, "Liquidity Traps and Jobless Recoveries," *American Economic Journal: Macroeconomics 9,* January 2017, 165-204.

Schmitt-Grohé, Stephanie, and Martín Uribe, "Technical Appendix to Heterogeneous Downward Nominal Wage Rigidity: Foundations of Phillips's Phillips Curve," manuscript, Columbia University, December 2022.

Smets, Frank and Raf Wouters, "Shocks and Frictions in US Business Cycles: A Bayesian DSGE Approach," *American Economic Review 97,* June 2007, 586–606.

Tobin, James, "Inflation and Unemployment," *American Economic Review 62,* March 1972, 1–18.