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On the Equivalence of Price and Wage Staggering: Extension and Implication for Persistence

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This paper examines the equivalence of staggered-price and staggered-wage models in generating persistence. Under certain parameter restrictions, I show that a sticky-price model that includes firm specific labor and labor adjustment costs is observationally equivalent to a sticky-wage model featuring habit in leisure with respect to all aggregate quantities and price inflation. Each form of labor stickiness interacts positively with the nominal rigidity with which it is combined to enhance output persistence. The results suggest that labor demand rigidity has a small impact on the propagation of monetary shocks to real activity. However, it plays an important role in shaping price dynamics. I also show that a sticky-wage model that assumes temporal substitution of leisure periods is able to match the empirical low persistence in wage inflation.

Keywords: Firm-specific labor; Endogenous persistence; Price and wage rigidities

JEL classification: E24; E32; E52

I. Introduction

The short run effects of monetary policy shocks on real activity has been one of the central issues in monetary economics for at least the past two decades, see, e.g., Christiano et al. (2005). Two competing views have been identified by the literature. The first view emphasizes the role of price rigidity in the transmission of monetary shocks (See, e.g., Yun, 1996; and Dotsey and King, 2006). The second view defended by Fischer (1977) studies the macroeconomic implications of nominal wage rigidity (see e.g., Cho and Cooley, 1995).

In an influential paper, Chari et al. (2000) showed that a standard sticky-price model with a reasonable degree of price rigidity fails to produce sizeable real effects of monetary policy shocks. In an estimated dynamic general equilibrium (DGE) model with price and wage contracts, Christiano et al. (2005) emphasized the importance of wage rigidity in accounting for the response of the economy to a monetary policy shock. Huang and Liu (2002) showed that, for the same degree of nominal rigidity, a sticky-wage model is more able to produce persistent real effects of monetary shocks than a sticky-price model. However, Huang and Liu's result hinges on the assumption that labor markets are integrated. But once we allow for labor to be firm specific, one can show that it is possible to achieve an observational equivalence of staggered price setting and staggered wage setting with respect to all aggregate quantities and price inflation. In fact if we assume that the elasticity of substitution between differentiated goods and

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the elasticity of substitution between differentiated labor skills are equal, a sticky-price model in which labor is firm specific is able to produce the same amount of persistence as a sticky-wage model of the same degree of nominal rigidity.

This equivalence result was pioneered by Edge (2002) under Taylor staggered contracts. Yet, it could be gleaned from the derivations of Huang and Liu (2002) and Woodford (2003, Chapter 3). Huang and Liu (2002) derived and compared the optimal wage and price decisions under Taylor contracts as well as the assumption that labor is firm specific in both staggered models. Using Calvo (1983) staggered pricing, Woodford (2003) also derived and compared the price-Phillips curve under labor specificities with the wage-Phillips curve under integrated labor markets.

This paper revisits and extends the basic equivalence result of price and wage staggering under Calvo contracts. More specifically, I explore the robustness of such result to the introduction of labor rigidity into both basic staggered models. I allow for labor adjustment costs in the sticky-price model while I introduce habit formation in leisure in the sticky-wage model. The goal is to provide the theoretical conditions, if any, under which the equivalence of the two types of staggering mechanisms is maintained.

Labor rigidity has been supported by a large body of empirical research. First, several studies have investigated the existence of adjustment costs in labor demand. See e.g., Hamermesh (1989, 1995), Sbordone (1996), and Cooper et al. (2004).[1] Second, many authors provided empirical support for habit in leisure. See, e.g., Eichenbaum et al. (1988), Braun and Evans (1995), and Wen (1998). However, little has been done to explore the macroeconomic implications of introducing labor stickiness into DGE models with nominal rigidities, see, e.g., Neiss and Pappa (2005) and Janko (2008). Neiss and Pappa combined habit in leisure with sticky prices while Janko incorporated labor adjustment costs into a sticky-wage model. This paper can then be viewed as a contribution to this strand of literature.

This equivalence result is crucial since it implies that once labor is allowed to be firm specific, sticky-price and sticky-wage models become equally relevant for monetary policy analysis. On the other hand, staggered wage setting has been criticized in the literature in many respects. First, a well-known issue articulated in Barro (1977) is that the data reveal the existence of long-term implicit contracts between firms and workers. Under such contracts, labor demand may be unaffected by wages. However, wages are in general allocative in staggered-wage models. Second, most of the existing sticky-wage models assume a symmetric rigidity; whereas, empirical evidence indicates that nominal wages are more downwardly rigid (see, Kim and Ruge-Murcia, 2009; and the references therein). Yet, little evidence exists suggesting asymmetric price adjustment costs (see, for example, Bergen et al., 2008). Finally, staggered-wage models predict countercyclical real wages in response to monetary shocks that are at odds with the data. Thus, sticky-price models, by providing a better description of the data, become a more powerful tool for policy analysis.[2]

The main findings of the paper can be summarized as follows. First, it is shown that, under certain parameter restrictions, a staggered-price model in which labor is firm specific and costly to

[1] The idea that labor might be costly to adjust goes back at least to Oi (1962). See Hamermesh and Pfann (1996) for an early survey.

[2] This message must be taken with some caution. Chari et al. (2009) argued that some DGE models with price and/or wage rigidities as typified by the work of Smets and Wouters (2007) are not yet useful for monetary policy analysis. The reason for this is that they include dubious features and questionable structural shocks such as backward price indexation and wage-markup shocks.

adjust is observationally equivalent to a staggered-wage model featuring habit in leisure with respect to all common aggregate variables (i.e., output, hours worked, nominal interest rate, and price inflation) except for nominal wages. Empirically, these parameter conditions seem plausible. Each form of labor stickiness interacts positively with the nominal rigidity with which it is combined to increase endogenous output persistence. The results reveal that labor demand rigidity has a small impact on the propagation of monetary shocks to real activity. It plays a significant role in increasing price inflation persistence, however.

Second, under sticky wages, the results suggest that in order to obtain the low persistence in wage inflation as found in the data, periods of leisure must be temporal substitutes across all leads and lags. This assumption has been supported by Kydland and Prescott (1982) in a real business cycle model.

To summarize, the contribution of this paper to the business-cycle literature is threefold. First, the paper provides for the first time an extension of the theoretical framework of the equivalence result. Needless to say, such a result is relevant for monetary policy analysis. Second, the paper presents the first rigorous study showing that introducing labor rigidities into a standard New Keynesian model can have considerable implications on macroeconomic persistence. Third, to my best knowledge, the paper proposes the first business-cycle model that is able to explain the persistence in nominal wages.

The remainder of the paper is organized as follows: Section II studies the equivalence of price and wage staggering under the case of labor rigidity as well as the case of labor flexibility; Section III proposes a staggered-wage model that is able to match the empirical persistence in wage inflation; and Section IV provides some conclusions.

II. Extension of the Equivalence of Price and Wage Staggering

The following is a description of the main building blocks of two business-cycle models. The first is a sticky-wage model that features a non-time separability in leisure choices, and the second is a sticky-price model in which labor is assumed to be firm-specific and costly to adjust.

A. The Sticky Wage Model

The economy is composed of a large number of intermediate goods-producing firms indexed by j on the continuum from 0 to 1, a finished goods-producing firm, a representative household, a labor aggregator, a government and a central bank. Following Blanchard and Kiyotaki (1987), we assume monopolistic competition in both goods and labor markets.

A.1. Household

It is assumed that the representative household has a large number of members indexed by i on the continuum from 0 to 1, each of which supplies a differentiated labor skill $H_{i,t}$ to a representative labor aggregator. The latter combines the differentiated skills into a composite labor of the form

$$H_t = \left[\int_0^1 H_{i,t}^{\frac{\theta_w - 1}{\theta_w}} di \right]^{\frac{\theta_w}{\theta_w - 1}}, \tag{1}$$

where $\theta_w > 1$ denotes the elasticity of substitution between differentiated labor skills. The demand schedule for labor service i is given by

$$H_{i,t} = \left(\frac{W_{i,t}}{W_t}\right)^{-\theta_w} H_t, \tag{2}$$

where $W_{i,t}$ is the nominal wage set by the member i. The aggregate wage index W_t is given by

$$W_t = \left[\int_0^1 W_{i,t}^{1-\theta_w} di\right]^{\frac{1}{1-\theta_w}}. \tag{3}$$

The preferences of the household are represented by the expected utility function

$$E_0 \sum_{t=0}^{\infty} \beta^t U(C_t, C_{t-1}, H_{i,t}, H_{i,t-1}), \tag{4}$$

where

$$U(C_t, C_{t-1}, H_{i,t}, H_{i,t-1}) = \left[\ln(C_t - \sigma_c C_{t-1}) - \int_0^1 \left(\frac{\chi}{1+\eta}(H_{i,t} - \varphi H_{i,t-1})^{1+\eta}\right) di\right],$$

$\beta \in [0, 1]$ is the subjective discount factor, C_t is an aggregate of consumption goods at period t. The coefficient $\sigma_c \in [0, 1]$ captures habit formation in consumption. The coefficient $\varphi \in [0, 1]$ measures habit formation in leisure. η and χ are two positive constants.

The household enters period t with bond holdings B_{t-1}. It is assumed that labor income is subsidized at the net rate δ_w. Each member i of the household supplies $H_{i,t}$ at the nominal income $(1+\delta_w)W_{i,t}$. The household purchases B_t units of bonds, C_t units of the aggregate consumption goods at the nominal price P_t from the finished goods-producing firm. At the end of period t, the household receives total nominal profits D_t from the intermediate goods-producing firms and pays a nominal lump-sum taxes T_t to the government. Let R_t be the gross nominal interest rate between periods t and t+1. The household faces the flow budget constraint

$$P_t C_t + \frac{B_t}{R_t} \leq B_{t-1} + \int_0^1 (1+\delta_w) W_{i,t} H_{i,t} di + D_t - T_t. \tag{5}$$

It is assumed that all members of the household set their wages according to Calvo-style staggered contracts. In each period, each member faces a probability $1-\xi_w$ of being able to adjust his or her nominal wage. The adjusting member i in period t chooses the following optimal relative wage W_t^*/W_t given by

$$\frac{W_t^*}{W_t} = \mu_w \frac{\sum_{\tau=0}^{\infty}(\beta\xi_w)^\tau E_t\left[\left(\frac{W_{t+\tau}}{W_t}\right)^{\theta_w} MRS_{i,t+\tau} H_{t+\tau}\right]}{\sum_{\tau=0}^{\infty}(\beta\xi_w)^\tau E_t\left[\left(\frac{W_{t+\tau}}{W_t}\right)^{\theta_w - 1}\left(\frac{W_{t+\tau}}{P_{t+\tau}}\right) H_{t+\tau}\right]}, \tag{6}$$

where $\mu_w = \theta_w/[(\theta_w-1)(1+\delta_w)] > 1$ denotes the steady state markup of real wage over marginal rate of substitution of consumption for leisure, and $MRS_{i,t}$ denotes the marginal rate of substitution of member i. Equation (6) indicates that, up to a first order approximation, the member's optimal relative wage is a discounted distributed lead of his or her expected marginal rate of substitution. If wages were fully flexible ($\xi_w \to 0$), equation (6) reduces to the static condition

$$\frac{W_t}{P_t} = \mu_w MRS_t, \tag{7}$$

where MRS_t denotes the aggregate marginal rate of substitution. The aggregate wage index in (3) can be expressed as

$$W_t^{1-\theta_w} = (1-\xi_w)W_t^{*1-\theta_w} + \xi_w W_{t-1}^{1-\theta_w}. \tag{8}$$

A.2. Firms

It is assumed that the representative final goods-producing firm acts competitively in the final good market. It produces a quantity Y_t of the finished good using the Dixit-Stiglitz aggregator

$$Y_t \leq \left[\int_0^1 Y_{j,t}^{\frac{\theta_p-1}{\theta_p}} dj\right]^{\frac{\theta_p}{\theta_p-1}}, \tag{9}$$

where $Y_{j,t}$ denotes the quantity of good of type j used in the production of the composite good, and $\theta_p > 1$ denotes the elasticity of substitution between differentiated goods. The finished goods-producing firm purchases $Y_{j,t}$ at the nominal cost $P_{j,t}$. The first order condition for its maximization problem is given by

$$Y_{j,t} = \left(\frac{P_{j,t}}{P_t}\right)^{-\theta_p} Y_t. \tag{10}$$

The absence of profits implies that

$$P_t = \left[\int_0^1 P_{j,t}^{1-\theta_p} dj\right]^{\frac{1}{1-\theta_p}}. \tag{11}$$

Each intermediate goods-producing firm j produces a quantity $Y_{j,t}$ of the good j using a quantity $H_{j,t}$ of a labor input according to the technology

$$Y_{j,t} = H_{j,t}. \tag{12}$$

It is assumed that production is subsidized at the net rate δ_p. Price flexibility implies that

$$P_t = \mu_p W_t, \tag{13}$$

where $\mu_p = \theta_p/[(\theta_p-1)(1+\delta_p)] > 1$ denotes the steady state markup of price over nominal wage.

A.3. Monetary and Fiscal Policy

In what follows, a lower-case variable denotes the log-deviation of the upper-case variable from its steady-state value, and a variable without time subscript denotes its steady-state value. It is assumed that the central bank conducts monetary policy by using the following interest rate rule

$$r_t = \rho_r r_{t-1} + (1-\rho_r)\rho_\pi \pi_t + (1-\rho_r)\rho_y y_t + \varepsilon_{r,t}, \tag{14}$$

where $\pi_t = p_t - p_{t-1}$ denotes the logarithm of price inflation, and $\varepsilon_{r,t}$ is a zero-mean, serially uncorrelated, and normally distributed variable with standard deviation σ_r. $\varepsilon_{r,t}$ plays the role of a monetary policy shock. The parameters $\rho_\pi > 0$ and $\rho_y > 0$ are respectively the long-run responses of the central bank to deviations of inflation and output from their steady state values. The coefficient ρ_r captures inertia in the nominal interest rate movements.[3]

[3] Evidence for short-term interest-rate smoothing is provided by a growing empirical literature, see e.g., Rudebusch (1995). An alternative policy is an active (discretionary) monetary policy, i.e., through open market operations. Kia (2010) argued that the choice between interest-rate smoothing specification and active policy depends on the behavior of agents in the money market. Kia suggested that when agents are forward-looking, as found in the data, interest-rate smoothing would be optimal.

It is assumed that the budget of the government is balanced every period. So the lump-sum taxes are equal to the subsidies to the household and firms.

The aggregate resource constraint of the economy is simply given by

$$C_t = Y_t. \tag{15}$$

B. The Sticky Price Model

Now since our focus is on rigid prices, it is assumed that wages are fully flexible. As in Woodford (2003), the assumption is that each member i of the household is coupled with a firm j along the unit interval and he or she is allowed to supply his or her labor to that firm only.[4] Firms set their prices according to Calvo-staggered contracts.[5] In each period, each firm faces a probability $1-\xi_p$ of being able to adjust its nominal price $P_{j,t}$. The adjusting firm j in period t chooses the following optimal relative price P_t^*/P_t given by

$$\frac{P_t^*}{P_t} = \mu_p \frac{\sum_{\tau=0}^{\infty} \xi_p^\tau \beta^\tau E_t \left[\left(\frac{\Lambda_{t+\tau}}{\Lambda_t} \right) \left(\frac{P_{t+\tau}}{P_t} \right)^{\theta} \left(\frac{W_{j,t+\tau}}{P_{t+\tau}} \right) Y_{t+\tau} \right]}{\sum_{\tau=0}^{\infty} \xi_p^\tau \beta^\tau E_t \left[\left(\frac{\Lambda_{t+\tau}}{\Lambda_t} \right) \left(\frac{P_{t+\tau}}{P_t} \right)^{\theta-1} Y_{t+\tau} \right]}, \tag{16}$$

where Λ_t determines the Lagrange multiplier associated with the budget constraint of the household (5), and $\beta^\tau E_t(\Lambda_{t+\tau}/\Lambda_t)$ is the expected discount factor. Equation (16) indicates that, up to a first order approximation, the firm's optimal relative price is a discounted distributed lead of its expected real wage. The aggregate price level in (11) can be written as

$$P_t^{1-\theta_p} = (1-\xi_p) P_t^{*1-\theta_p} + \xi_p P_{t-1}^{1-\theta_p}. \tag{17}$$

Following Sbordone (1996), it is assumed that total nominal labor costs are

$$LC_{j,t} = W_{j,t} H_{j,t} \left[1 + \Psi\left(\gamma_{H,jt} \right) \right], \tag{18}$$

where $\gamma_{H,jt} = H_{j,t}/H_{j,t-1}$. The function $\Psi(.)$ is convex and satisfies: $\Psi(1) = \Psi'(1) = 0$. It is not necessary to provide any other information about $\Psi(.)$. The optimality condition for labor demand is given by

$$MC_{j,t} = W_{j,t}\Omega_{j,t}, \tag{19}$$

where $\Omega_{j,t} = [1+\Psi(\gamma_{H,jt})+\gamma_{H,jt}\Psi'(\gamma_{H,jt})-\beta E_t(\gamma^2_{H,jt+1}(\Lambda_{t+1}/\Lambda_t)(W_{t+1}/W_t)\Psi'(\gamma_{H,jt+1}))]$, and $MC_{j,t}$ denotes the nominal marginal cost of firm j.

The rest of the model is similar to the one described above.

[4] This way of modelling labor specificities has been used by Edge (2002) and Huang (2006). Huang and Lui (2002) proposed another way of introducing labor specificities that is appropriate for an environment with staggered wage-setting decisions.

[5] In this paper, I used the conventional Calvo framework for its popularity. One disadvantage of the time-dependent (Calvo) pricing is that it rests on the exogeneity of the frequency of price adjustment. A better alternative is state-dependent approach in which the frequency of price adjustment is endogenous. Gertler and Leahy (2008) have derived a Phillips curve based on state-dependent pricing that has the same form as the Calvo Phillips curve. Interestingly, Gertler and Leahy showed that the dynamics of output implied by the state-dependent model are close to those implied by the time-dependent model once they introduce real rigidities in the form of firm-specific labor.

C. Establishing the Equivalence

C.1. Case of Labor Flexibility

This section briefly exposes the equivalence result under labor flexibility. So I abstract from leisure habit in the sticky-wage model and from labor adjustment costs in the sticky-price model. For ease of exposition, σ_c is set to 0.

Starting with the sticky-wage model, the familiar wage-Phillips curve is given by

$$\pi_{w,t} = \beta E_t \pi_{w,t+1} + \frac{(1-\beta\xi_w)(1-\xi_w)}{\xi_w(1+\theta_w\eta)} mrs_t, \tag{20}$$

where $\pi_{w,t} = w_t - w_{t-1}$ denotes the logarithm of wage inflation.

Turning to the sticky-price model, it is straightforward to show that the price-Phillips curve takes the form

$$\pi_t = \beta E_t \pi_{t+1} + \frac{(1-\beta\xi_p)(1-\xi_p)}{\xi_p(1+\theta_p\eta)}(w_t - p_t). \tag{21}$$

Let define Ω_k as

$$\Omega_k = \frac{(1-\beta\xi_k)(1-\xi_k)}{\xi_k(1+\theta_k\eta)}(1+\eta), \qquad k = (p, w).$$

Ω_p and Ω_w denote respectively the elasticity of price and wage inflation to output and are considered as useful measures of output persistence. For example, a lower value of Ω_p (Ω_w) implies a smaller adjustment of prices (wages) in response to changes in output, and consequently a longer-lived response of output to a monetary policy shock.

It can be seen that equations (20) and (21) are of the same form. What is more, if $\theta_p = \theta_w$ and $\xi_p = \xi_w$, then $\Omega_p = \Omega_w$ and the two models yield the same prediction about prices dynamics.[6] Moreover, both models share the same other equilibrium conditions and, consequently have identical implications for output and nominal interest rate dynamics. In other words, one can obtain an observational equivalence of the staggered-price model augmented by a firm-specific labor assumption and the staggered-wage model in generating persistence. This result was originally proposed by Edge (2002) under Taylor staggered contracts.[7]

Now some intuitions behind the obtained Phillips curves are provided starting with the wage-Phillips curve. Following an expansionary monetary policy shock, each member of the household raises his or her optimal relative nominal wage since his or her marginal rate of substitution rises due to an increase in his or her wage income and a higher demand for his or her labor skills. In the same time, an increase in the relative wage of the representative member reduces his or her relative labor demand by a factor θ_w and his or her marginal rate of substitution by a factor η, which attenuates the rise in his or her optimal relative wage insofar as the latter is determined by the marginal rate of substitution. As a result, the increase in the nominal wage index is dampened. This is why the elasticity of wage inflation to aggregate marginal rate of substitution in (20) is a decreasing function of both θ_w and η.

Under sticky prices, the labor demand of each firm for its specific labor is tightly linked to the demand facing the firm for its output, which in turn depends negatively on its relative price.

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[6] Notice that in the sticky-wage model since prices are fully flexible, the dynamics of nominal wages and prices are identical. Notice also that in the sticky-price model, the real wage is equal to the marginal rate of substitution: $(w_t - p_t) = mrs_t = (1+\eta)y_t$.

[7] See also Huang and Liu (2002) and Woodford (2003, chapter 3).

An increase in the firm's relative price caused by an expansionary monetary shock will reduce the demand for its output by a factor θ_p. This creates a counter-forcing (downward) shift in the specific labor demand schedule, which reduces the real wage facing the firm by a factor η. Thus, the increase in the firm's relative price is muted insofar as the price is determined by the real wage. This is why θ_p and η show up in the denominator of the elasticity of price inflation to real wage in (21). It is through the feedback effect between real wages and prices that firm-specific labor allows the staggered-price model to be as able as the staggered-wage model to generate persistence.

Before discussing the empirical validity of the equivalence of both staggering mechanisms, plausible values are assigned to the models' parameters of interest. β is set at $1.03^{-0.25}$, implying an annualized real interest rate of 3%. The estimates of Altonji (1986) suggest that the intertemporal (Frish) labor supply elasticity is lower than 0.35. However, Mulligan (1995, 1998) suggests a labor supply elasticity larger than one. In light of this, η is set to 4/3, which implies a labor supply elasticity of 0.75. Turning to θ_p, the literature suggests that the values 6, 10, and 21 are quite conventional (see e.g., Rotemberg and Woodford, 1995; and Basu and Fernald, 1997, 2000). A plausible range for θ_w is [2, 6] as suggested by the micro-based evidence presented in Griffin (1992, 1996). So the benchmark values for θ_w and θ_p are 4 and 10 respectively. ξ_w is set at 3/4 as suggested by Taylor (1999), implying an average duration of wage rigidity of 4 quarters. The consensus in the literature about the value of ξ_p is that it lies between 1/3 and 5/6.[8] Accordingly, I set ξ_p = 2/3, which means that firms re-optimize prices, on average, every 3 quarters.

Table 1 displays values of Ω_k for several values of θ_k and ξ_k, for $k = \{p,w\}$. It can be seen that the impact of a change in the degree of nominal rigidity on Ω_k is larger than the impact of a change in the degree of market power. Under the benchmark calibration, Ω_w and Ω_p have similar values (about 0.03) because the effect of a lower Calvo probability in the staggered-price model is offset by a lower elasticity of substitution in the sticky-wage model.

Table 1: Wage and Price Inflation Elasticities to Output

Values of Ωw			
	$\xi_w = 2/3$	$\xi_w = 3/4$	$\xi_w = 5/6$
$\theta_w = 2$	0.1076	0.0542	0.0220
$\theta_w = 4$	0.0623	**0.0314**	0.0127
$\theta_w = 6$	0.0438	0.0221	0.0090

Values of Ωp				
	$\xi_p = 1/3$	$\xi_p = 2/3$	$\xi_p = 3/4$	$\xi_p = 5/6$
$\theta_p = 6$	0.3470	0.0438	0.0221	0.0090
$\theta_p = 10$	0.2179	**0.0275**	0.0139	0.0056
$\theta_p = 21$	0.1077	0.0136	0.0069	0.0028

[8] Bils and Klenow (2004) found that the median duration between price changes is 1.5 quarters, i.e., ξ_p = 1/3 . Christiano et al. (2005) provided a benchmark estimate for ξ_p of 3/5. See also the survey of evidence in Taylor (1999) and Wolman (2007).

C.2. Case of Labor Rigidity

Let's start with the sticky-wage model. In the Appendix, it is shown that the dynamics of nominal wages are described by

$$\pi_{w,t} = \kappa_1 E_t \pi_{w,t+2} + \kappa_2 E_t \pi_{w,t+1} + \kappa_3 \pi_{w,t-1} + \kappa_4 mrs_t, \qquad (22)$$

where

$$\kappa_1 = -\beta^2 \kappa_3,$$

$$\kappa_2 = \frac{\beta[1 + \theta_w(\psi_w + \mathrm{h}_w)]}{[1 + \theta_w(\psi_w + \beta \mathrm{h}_w)]},$$

$$\kappa_3 = \frac{\theta_w \mathrm{h}_w}{[1 + \theta_w(\psi_w + \beta \mathrm{h}_w)]},$$

$$\kappa_4 = \frac{(1 - \beta\xi_w)(1 - \xi_w)}{\xi_w[1 + \theta_w(\psi_w + \beta \mathrm{h}_w)]},$$

with $\mathrm{h}_w = \eta\varphi/[(1-\varphi)(1-\beta\varphi)]$, and $\psi_w = \eta+(1+\beta)\mathrm{h}_w$.

Notice first that if φ is set to zero, equation (22) reduces to equation (20). Equation (22) indicates that wage inflation exhibits richer dynamics in presence of non-time-separable utility in leisure. The coefficient φ governs the persistence in wage inflation. The more φ is high, the more persistent $\pi_{w,t}$ will be.

To understand the nature of nominal wages dynamics in equation (22), it is useful to look at the dynamics of the aggregate marginal rate of substitution. The latter is given by

$$mrs_t = \eta h_t - \lambda_t + \Xi_t^w, \qquad (23)$$

where $\Xi_t^w = \mathrm{h}_w(h_t - h_{t-1}) - \beta \mathrm{h}_w(E_t h_{t+1} - h_t)$. Ξ_t^w is interpreted as the costs of changing hours supplied in terms of utility. Assume that in the past periods the economy has been buffeted by an expansionary monetary shock raising labor demand. High lagged levels of hours are accompanied with high lagged wage inflation. So in the current period, hours also tend to be high since the current costs of changing hours supplied are temporarily low. Then the current wage inflation also tends to be high. When current hours are high, they are expected to fall in the subsequent periods. Such a decline in expected hours supplied will be accompanied by lower nominal wages.

Turning to the sticky-price model, it is established in the Appendix that the price-Phillips curve takes the form

$$\pi_t = \upsilon_1 E_t \pi_{t+2} + \upsilon_2 E_t \pi_{t+1} + \upsilon_3 \pi_{t-1} + \upsilon_4 (mc_t - p_t), \qquad (24)$$

where

$$\upsilon_1 = -\beta^2 \upsilon_3,$$

$$\upsilon_2 = \frac{\beta[1 + \theta_p(\psi_p + \mathrm{h}_p)]}{[1 + \theta_p(\psi_p + \beta \mathrm{h}_p)]},$$

$$\upsilon_3 = \frac{\theta_p \mathrm{h}_p}{[1 + \theta_p(\psi_p + \beta \mathrm{h}_p)]},$$

$$\upsilon_4 = \frac{(1 - \beta\xi_p)(1 - \xi_p)}{\xi_p[1 + \theta_p(\psi_p + \beta \mathrm{h}_p)]},$$

with $\mathrm{h}_p = \Psi''(1)$, and $\psi_p = \eta+(1+\beta)\mathrm{h}_p$.

The parameter $\Psi''(1)$ controls the curvature of labor adjustment costs. If $\Psi''(1)$ is set to zero, equation (24) collapses to equation (21). Therefore, once labor adjustment costs are introduced into a sticky-price model with labor specificities, one is able to obtain more endogenous persistence in price inflation (π_t depends on its own lag). The more $\Psi''(1)$ is high, the more persistent π_t will be. It is worth noting that even with integrated labor markets, the presence of rigid labor demand gives rise to a price-Phillips curve that is very close to equation (24) (see the Appendix). Similar concerns to those stated above apply to understand the form taken by equation (24).[9]

It is important to mention at this level that the nature of inflation dynamics has been one of the most intensely debated topics in macroeconomics (see, e.g., Fuhrer and Moore, 1995). The literature offers different ways of inducing inertia in price changes. For example, through an ad-hoc assumption of full-price indexation to lagged inflation as in Christiano et al. (2005); or through partial-price indexation to lagged inflation as in Smets and Wouters (2007); or through the existence of backward-looking firms as in Galí and Gertler (1999); or through the presence of persistent shocks as in Ireland (2003). Chari et al. (2009) argued that backward-price indexation is at odds with microeconomic evidence on prices and consequently should be dropped from DGE models. In response to Chari et al.'s critique, it is shown here that allowing for labor-adjustment costs in a sticky-price model constitutes an empirically plausible micro-founded mechanism to induce inflation persistence.[10]

Again, notice that the Phillips curves (22) and (24) are of the same form. A key result of the paper is that in presence of a labor rigidity, the observational equivalence of the two staggered models is maintained at least in theory. The conditions of this equivalence are $\theta_p = \theta_w$, $\xi_p = \xi_w$, and $h_p = h_w$.

Assume for now that $\theta_p = \theta_w = 6$, and $\xi_p = \xi_w = 3/4$, which is considered as the limiting case that is supported empirically. Available evidence concerning habit in leisure suggests that φ lies between 0.35 and 0.80 (see e.g., Eichenbaum et al., 1988; Bover, 1991; Braun and Evans, 1995; and Wen, 1998). With $0.35 \leq \varphi \leq 0.80$, the condition $h_p = h_w$ is satisfied when $1.10 \leq \Psi''(1) \leq 25.90$. Let set φ to 0.60. The value of $\Psi''(1)$ that is needed to achieve the equivalence is about 4.95, which is close to the value of 4 suggested by Sbordone (1996, 2002). Then the equivalence seems to hold from an empirical point of view.

D. Impulse Response Analysis

The remaining parameters are calibrated as follows. The consumption habit parameter σ_c is set to 0.8. The labor and production subsidies are chosen to exactly offset the monopolistic distortions in labor and goods markets, i.e., $\delta_w = 1/3$, and $\delta_p = 1/9$. The parameters of the interest-rate rule are calibrated as follows: $\rho_r = 0.85$, in line with the estimates reported in Fuhrer (1997), and Clarida et al. (2000); $\rho_\pi = 1.5$; and $\rho_y = 0.25$. The standard deviation of the monetary policy shock σ_r is set to 0.003. To compute the impulse response functions, I take a log-linear

[9] One can show that the average real marginal cost is given by $mc_t - p_t = (w_t - p_t) + \Xi_t^p$, where $\Xi_t^p = \Psi''(1)(h_t - h_{t-1}) - \beta\Psi''(1)(E_t h_{t+1} - h_t)$. Ξ_t^p *is* interpreted as the costs associated with rapid changes of labor demand.

[10] The coefficient on lagged inflation implied by the Phillips curve derived by Christiano et al. (2005) is about 0.5, while the coefficient implied by the hybrid Phillips curve of Galí and Gertler (1999) is about 0.25. Using the equation (24), and setting $\Psi''(1) = 6$, the value of υ_3 *is* about 0.31. As it is shown below, this value is high enough to allow the model to match the observed persistence in inflation.

approximation of all the equilibrium conditions around the steady state and solve the resulting system of linear difference equations using the methods outlined by Klein (2000).

Given the equivalence of the two types of staggering mechanisms, the analysis is limited to the sticky-price model. $\Psi''(1)$ is set to 6, which agrees with Sbordone's (1996) estimates.

Figure 1 depicts the impulse responses of output and inflation to a negative interest rate shock under both cases with and without labor adjustment costs. It can be seen that both specifications yield similar predictions about output dynamics. Output exhibits a hump-shaped response, in line with the VAR literature (see, for example, Christiano et al., 2005). Notice that the initial response of output is marginally larger in presence of labor-demand rigidity. The main difference between the two models lies in the response of inflation to the shock. Under labor flexibility, after an initial increase, inflation dies out gradually. Once labor adjustment costs are allowed for, inflation exhibits hump-shaped patterns. It is concluded, therefore, that including costs of adjusting labor demand into a sticky-price model with segmented labor markets has a trivial impact on the size of the real effects of monetary policy disturbances but an important effect on inflation persistence.

The size of real effects of monetary shocks in each version of the sticky-price model can be quantified by computing the *half-life* of output as popularized by Chari et al. (2000). To construct the empirical *half-life* of output, as in Chari et al. (2000), it is assumed that the log of real per capita GDP in deviations from a fitted quadratic trend is best represented by an AR(2) process.[11] The estimation covers the period 1970:I-2006:IV (the results are not shown to save space). It is found that the *half-life* of output is 10.70 quarters, which is close to the value of 10 reported in Chari et al. (2000). The values of the *half-life* of output under the sticky-price model with and without labor adjustment costs are respectively 10.47 and 10.41, both are consistent with the data.

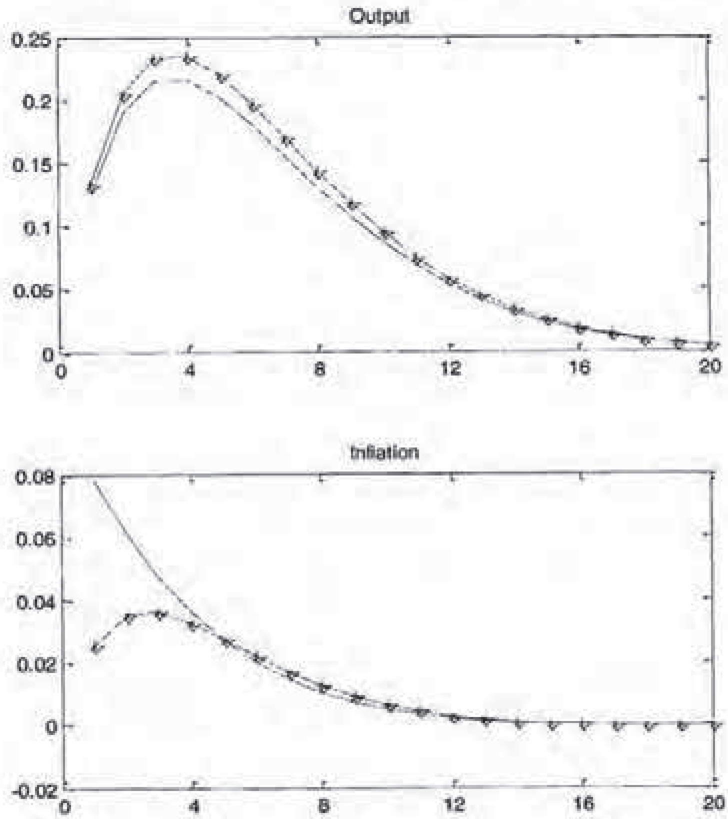
The presence of labor adjustment costs can help increase output persistence regardless of whether the labor is firm specific or not. To see this, consider that the economy is buffeted by an expansionary monetary shock. When labor demand is costly to adjust, the individual real marginal cost is no longer constant; it depends positively on the firm's output. As shown graphically in Altig et al. (2005), this dependence of the real marginal cost on the firm's output leads to a smaller adjustment in the firm's price and, consequently, to a larger response of output on impact of the monetary shock.

Interestingly, Figure 1 shows a reinforcing interaction between labor specificities and labor-demand rigidity in generating output persistence. To understand this result, recall that an increase in the firm's relative price will reduce the demand for its output, and thereby the demand for its specific labor input. The real marginal cost becomes more responsive to hours in presence of labor adjustment costs. It declines by a factor ψ_p instead of η as is the case in which labor demand is fully flexible, (notice that $\psi_p > \eta$) which limits further the increase in the price level. Huang (2006) showed that introducing firm-specific factors into a sticky-price model featuring intermediate inputs "leads to a cancellation of much of the impact of each in propagating monetary shocks." Moreover, Dotsey and King (2005) showed that firm-specific labor lowers output persistence in a state-dependent pricing environment. Taken together, these results cast doubt on the robustness of labor specificities in propagating monetary shocks.

[11] The data is available online at the Federal Reserve Bank of St. Louis. Output is measured by real GDP (mnemonic GDPC1). Output is converted into per capita terms by dividing by the civilian noninstitutional population 16 years and above (mnemonic CNP16OV).

Similarly, in the staggered-wage model, labor supply rigidity helps enhance output persistence. To understand this result, recall that in response to a monetary policy shock each member of the household raises his or her optimal relative nominal wage, which reduces his or her relative labor demand. Habit in leisure increases the smoothness of hours supplied relatively to the marginal rate of substitution. Consequently, the latter is reduced by a factor ψ_w instead of η as is the case in which labor supply is fully flexible, (notice that $\psi_p > \eta$) which attenuates further the rise in the wage index.

Figure 1: Impulse Responses to a Monetary Policy Shock: Role of Sticky Labor



Note: Sticky-price model with $\Psi''(1) = 0$: solid line. Sticky-price model with $\Psi''(1) = 6$: line with asterisks.

E. Autocorrelation Functions

A standard way of measuring the magnitude of persistence is to compute the autocorrelation functions. Table 2 compares the autocorrelations of order 1 to 4 for output and inflation implied by both versions of the sticky-price model (with and without labor adjustment costs) with their empirical counterparts.[12] Notice that in the data output and inflation are highly autocorrelated.[13] The results suggest that both specifications succeed in replicating the persistence in output. But the

[12] I use the same series for output as defined earlier. Inflation is measured by the first log-difference of the price level as measured by the implicit price deflator of GDP (mnemonic GDPDEF). The sample period is 1970:I-2006:IV.
[13] See Fuhrer and Moore (1995), and Ireland (2003).

persistence in inflation is better captured by the sticky-labor specification. These findings are consistent with the impulse response analysis presented above.

Table 2: Autocorrelations: Sticky-Price Models vs Data

	Sticky Price Models								Data			
	$\Psi''(1)=0$				$\Psi''(1)=6$							
	Autocorrelations				Autocorrelations				Autocorrelations			
Variable	1	2	3	4	1	2	3	4	1	2	3	4
Output	0.9580	0.8696	0.7599	0.6449	0.9587	0.8707	0.7609	0.6454	0.9379	0.8496	0.7444	0.6280
Inflation	0.7687	0.5820	0.4339	0.3181	0.9267	0.7905	0.6383	0.4941	0.8711	0.8247	0.7987	0.7839

III. Nominal Wages Dynamics

Central banks are acutely interested in the price inflation process because one of their main tasks is to promote price stability. Several important steps have been made in the understanding of prices dynamics in recent years. However, little has been done to explain some stylized facts about nominal wages behavior. This section constitutes a step toward this direction. More precisely, this section focuses on wage inflation persistence. Data reveal that, unlike price inflation, nominal wage growth is not highly autocorrelated (see the last rows of Table 3).[14]

Table 3: Autocorrelations: Sticky Wage Models (with $\varphi = 0$) vs Data

	Sticky Wage Models								Data			
	$\xi_w = 1/3$				$\rho_r = 0.60$							
	Autocorrelations				Autocorrelations				Autocorrelations			
Variable	1	2	3	4	1	2	3	4	1	2	3	4
Output	0.9064	0.7494	0.5875	0.4448	0.9121	0.7616	0.6038	0.4625	0.9379	0.8496	0.7444	0.6280
Inflation	0.5496	0.2954	0.1538	0.0763	0.5720	0.3218	0.1770	0.0944	0.5083	0.5029	0.4304	0.5001

Can one find a calibrated sticky-wage model that is able to match the first coefficients of the autocorrelation function of wage inflation? To answer this question, let's take the basic staggered-wage model, i.e., with $\varphi = 0$, as a starting point and conduct some sensitivity exercises.

In the first exercise, the probability ξ_w is reduced from 3/4 to 1/3. This will decrease considerably the autocorrelation coefficients of wage inflation (see the first rows of Tables 3 and 4). Even if this specification yields a more empirically plausible autocorrelation function of wage

[14] The nominal wage is measured by the compensation per hour in the nonfarm business sector (mnemonic COMPNFB). I also used the compensation per hour in the business sector (mnemonic HCOMPBS) and found that both series have nearly the same amount of persistence. The sample period is 1970:I-2006:IV.

inflation, it is not appealing for two reasons. First, an average duration of nominal wage contracts of 1.5 quarters is not supported by any micro-based or macro-based evidence. Second, such a decrease in the degree of wage rigidity comes with the cost of an important decline in output persistence. The *half-life* of output under the staggered-wage model with $\xi_w = 3/4$ and $\varphi = 0$ is about 10.25, which is close to its empirical value of 10.70. Setting ξ_w to 1/3 in this model reduces the output *half-life* to 5.81, which is far from the data.

In the second exercise, the smoothing parameter ρ_r is lowered from 0.85 to 0.60. This will reduce significantly the persistence in wage inflation as can be seen from the middle rows of Table 3. This solution is also not appealing because it reduces output persistence, lowering the *half-life* of output from 10.25 to 6.10.

In the last exercise, the assumption that $\varphi = 0$ is relaxed. The wage-Phillips curve (22) makes it clear that the sign of the parameter φ plays a key role in shaping nominal wage dynamics. Obviously, allowing for a leisure habit ($\varphi > 0$) increases the persistence in wage inflation, which makes the prediction of the model even more far from the data. However, it is possible to lower the persistence in wage inflation by assuming that φ is negative. Such an assumption has been considered by Kydland and Prescott (1982).[15] So following Kydland and Prescott, it is assumed that periods of leisure are intertemporal substitutes across all leads and lags, i.e., $-1 \leq \varphi < 0$. Kydland and Prescott provided a point estimate for φ of -0.50.[16] To my best knowledge, the labor economics literature does not offer any other estimates for the degree of intertemporal substitution of leisure. I set $\varphi = -0.60$, which is close to Kydland and Prescott's estimate. It can be seen from Table 4 that once one assumes that leisure periods are intertemporal substitutes, the model succeeds in matching the empirical autocorrelations of wage inflation without altering output persistence.

Table 4: Autocorrelations: Sticky Wage Models (allowing $\varphi \neq 0$) vs Data

	Sticky Wage Models								Data			
	$\varphi = 0$				$\varphi = -0.60$							
	Autocorrelations				Autocorrelations				Autocorrelations			
Variable	1	2	3	4	1	2	3	4	1	2	3	4
Output	0.9571	0.8672	0.7559	0.6399	0.9573	0.8675	0.7564	0.6405	0.9379	0.8496	0.7444	0.6280
Inflation	0.7645	0.5756	0.4265	0.3108	0.5626	0.5002	0.3449	0.2624	0.5083	0.5029	0.4304	0.5001

IV. Conclusion

This paper revisits and extends the basic equivalence result of price and wage staggering under Calvo contracts. The analysis shows that this equivalence result seems to be robust in theory as well as in practice to the introduction of labor rigidity.

[15] Kydland and Prescott (1982) provided a number of empirical arguments supporting the intertemporal substitution of leisure.

[16] Kydland and Prescott (1982) considered an infinite distributed lag. The value -0.50 corresponds to the sum of all the lag coefficients.

The paper shows that labor adjustment costs have a positive yet small impact on the propagation of monetary policy shocks to real activity in a model with rigid prices and firm specific labor. The major role played by these costs is to increase endogenous persistence in price inflation. So including these costs into New Keynesian models will help solve the persistence problem stressed by Chari et al. (2000), but it is more warranted on the basis of its implication for inflation dynamics.

In a staggered-wage model, it is found that allowing for intertemporal substitution of leisure helps reduce persistence in wage inflation bringing it to a level that is consistent with the data. This attempt to explain nominal wage dynamics must be taken with a grain of salt because it is believed in the recent literature that periods of leisure are complements rather than substitutes. If so, other mechanisms should be investigated with the goal of reconciling the prediction of a sticky-wage model about wage inflation persistence with that from the data. This task is left for future research.

References

Altig, D., L. J. Christiano, M. Eichenbaum, and J. L. Lindé. 2005. "Firm-Specific Capital, Nominal Rigidities and the Business Cycle." NBER Working Paper 11034.

Altonji, J. G. 1986. "Intertemporal Substitution in Labor Supply: Evidence from Micro Data." *Journal of Political Economy,* 94(3): S176-S215.

Barro, R. J. 1977. "Long-Term Contracting, Sticky Prices, and Monetary Policy." *Journal of Monetary Economics,* 3(3): 305-316.

Basu, S., and J. Fernald. 1997. "Returns to Scale in U.S. Production: Estimates and Implications." *Journal of Political Economy,* 105(2): 249-283.

Basu, S., and J. Fernald. 2000. "Why Is Productivity Procyclical? Why Do We Care?" *NBER Working Paper* 7940.

Bergen, M., H. (A.) Chen, D. Levy, and S. Ray. 2008. "Asymmetric Price Adjustment in the Small." *Journal of Monetary Economics,* 55(4): 728-737.

Bils, M., and P. J. Klenow. 2004. "Some Evidence on the Importance of Sticky Prices." *Journal of Political Economy,* 112(5): 947-985.

Blanchard, O. J., and K. Nobuhiro. 1987. "Monopolistic Competition and the Effects of Aggregate Demand." *American Economic Review,* 77(4): 647-666.

Bover, O. 1991. "Relaxing Intertemporal Separability: A Rational Habits Model of Labour Supply Estimated from Panel Data." *Journal of Labor Economics,* 9(1): 85-100.

Braun, R. A., and C. L. Evans. 1995. "Seasonality and Equilibrium Business Cycle Theories." *Journal of Economic Dynamics and Control,* 19(3): 503-531.

Calvo, G. A. 1983. "Staggered Prices in a Utility-Maximizing Framework." *Journal of Monetary Economics,* 12: 383-398.

Chari, V. V., P. J. Kehoe, and E. R. McGrattan. 2000. "Sticky Price Models of the Business Cycle: Can the Contract Multiplier Solve the Persistence Problem?" *Econometrica,* 68(5): 1151-1179.

Chari, V. V., P. J. Kehoe, and E. R. McGrattan. 2009. "New Keynesian Models: Not Yet Useful for Policy Analysis." *American Economic Journal: Macroeconomics,* 1(1): 242266.

Cho, J. O., and T. F. Cooley. 1995. "The Business Cycle with Nominal Contracts." *Economic Theory,* 6(1): 13-33.

Christiano, L. J., M. Eichenbaum, and C. L. Evans. 2005. "Nominal Rigidities and the Dynamic Effects of a Shock to Monetary Policy." *Journal of Political Economy,* 113(1): 1-45.

Clarida, R., J. Galí, and M. Gertler. 2000. "Monetary Policy Rules and Macroeconomic Stability: Evidence and Some Theory." *Quarterly Journal of Economics,* 115: 147-180.

Cooper, R. W., J. C. Haltiwanger, and J. Willis. 2004. "Dynamics of Labor Demand: Evidence from Plant-level Observations and Aggregate Implications." *NBER Working Paper* 10297.

Dotsey, M., and R. G. King. 2005. "Implications of State-Dependent Pricing for Dynamic Macroeconomic Models." *Journal of Monetary Economics,* 52(1): 213-242.

Dotsey, M., and R. G. King. 2006. "Pricing, Production, and Persistence." *Journal of the European Economic Association,* 4(5): 893-928.

Edge, R. M. 2002. "The Equivalence of Wage and Price Staggering in Monetary Business Cycle Models." *Review of Economic Dynamics,* 5(3): 559-585.

Eichenbaum, M. S., L. P. Hansen, and K. J. Singleton. 1988. "A Time Series Analysis of Representative Agent Models of Consumption and Leisure Choice under Uncertainty." *Quarterly Journal of Economics,* 103(1): 51-78.

Fischer, S. 1977. "Long-Term Contracts, Rational Expectations, and the Optimal Money Supply Rule." *Journal of Political Economy,* 85(1): 191-205.

Fuhrer, J. C. 1997. "Inflation/Output Variance Trade-Offs and Optimal Monetary Policy." *Journal of Money, Credit and Banking* 29(2): 214-234.

Fuhrer, J. C., and G. Moore. 1995. "Inflation Persistence." *Quarterly Journal of Economics,* 110(1): 127-159.

Galí, J., and M. Gertler. 1999. "Inflation Dynamics: A Structural Econometric Analysis." *Journal of Monetary Economics,* 44(2): 195-222.

Gertler, M., and J. Leahy. 2008. "A Phillips Curve with an Ss Foundation." *Journal of Political Economy,* 116(3): 533-572.

Griffin, P. B. 1992. "The Impact of Affirmative Action on Labor Demand: A Test of Some Implications of the Le Chatelier Principle." *Review of Economics and Statistics,* 74(2): 251-260.

Griffin, P. B. 1996. "Input Demand Elasticities for Heterogenous Labor: Firm-level Estimates and an Investigation into the Effects of Aggregation." *Southern Economic Journal,* 62(4): 889-901.

Hamermesh, D. S. 1989. "Labor Demand and the Structure of Adjustment Costs." *American Economic Review,* 79(4): 674-689.

Hamermesh, D. S. 1995. "Labour Demand and the Source of Adjustment Costs." *Economic Journal,* 105(430): 620-634.

Hamermesh, D. S., and G. A. Pfann. 1996. "Adjustment Costs in Factor Demand." *Journal of Economic Literature,* 34(3): 1264-1292.

Huang, K. X. D. 2006. "Specific Factors Meet Intermediate Inputs: Implications for the Persistence Problem." *Review of Economic Dynamics,* 9(3): 483-507.

Huang, K. X. D., and Z. Liu. 2002. "Staggered Price-Setting, Staggered Wage-Setting, and Business Cycle Persistence." *Journal of Monetary Economics,* 49(2): 405-433.

Ireland, P. N. 2003. "Endogenous Money or Sticky Prices?" *Journal of Monetary Economics,* 50: 1623-1648.

Janko, Z. 2008. "Nominal Wage Contracts, Labor Adjustment Costs and the Business Cycle." *Review of Economic Dynamics,* 11(2): 434-448.

Kia, A. 2010. "Overnight Monetary Policy in the United States: Active or Interest-Rate Smoothing?" *Journal of Macroeconomics,* 32: 378-391.

Kim, J., and F. J. Ruge-Murcia. 2009. "How Much Inflation is Necessary to Grease the Wheels?" *Journal of Monetary Economics,* 56: 365-377.

Klein, P. 2000. "Using the Generalized Schur Form to Solve a Multivariate Linear Rational Expectations Model." *Journal of Economic Dynamics and Control* 24(2000): 1405-1423.

Kydland, F. E., and E. C. Prescott. 1982. "Time to Build and Aggregate Fluctuations." *Econometrica,* 50(6): 1345-1370.

Mulligan, C. B. 1995. "The Intertemporal Substitution ofWork–What Does the Evidence Say?" *University of Chicago-Population Research Center Discussion Paper Series* 95-11.

Mulligan, C. B. 1998. "Substitution Over Time: Another Look at Life Cycle Labor Supply." *NBER Working Paper* 6585.

Neiss K. S., and E. Pappa. 2005. "Persistence Without Too Much Price Stickiness: The Role of Variable Factor Utilization." *Review of Economic Dynamics,* 8(1): 231-255.

Oi, W.Y. 1962. "Labor as a Quasi-Fixed Factor." *Journal of Political Economy* 70(6): 538-555.

Rotemberg, J. J., and M. Woodford. 1995. "Dynamic General Equilibrium Models with Imperfectly Competitive Product Markets." In *Frontiers of Business Cycle Research*, ed. Thomas F. Cooley, 243-293. Princeton: Princeton University Press.

Rudebusch, G. D. 1995. "Federal Reserve Interest Rate Targeting, Rational Expectations, and the Term Structure." *Journal of Monetary Economics,* 35(2): 245-274.

Sbordone, A. M. 1996. "Cyclical Productivity in a Model of Labor Hoarding." *Journal of Monetary Economics,* 38(2): 331-361.

Sbordone, A. M. 2002. "Prices and Unit Labor Costs: A New Test of Price Stickiness." *Journal of Monetary Economics,* 49(2): 265-292.

Smets, F., and R. Wouters. 2007. "Shocks and Frictions in US Business Cycles: A Bayesian DSGE Approach." *American Economic Review,* 97(3): 586-606.

Taylor, J. B. 1999. "Staggered Price and Wage Setting in Macroeconomics." In *Handbook of Macroeconomics*, eds. John B. Taylor and Michael Woodford, Vol. 1, 1009-1050. Amsterdam: North-Holland.

Wen, Y. 1998. "Can a Real Business Cycle Model Pass the Watson Test?" *Journal of Monetary Economics,* 42(1): 185-203.

Wolman, A. L. 2007. "The Frequency and Costs of Individual Price Adjustment." *Managerial and Decision Economics,* 28(6): 531-552.

Woodford, M. 2003. *Interest and Prices: Foundations of a Theory of Monetary Policy.* Princeton and Oxford: Princeton University Press.

Yun, T. 1996. "Nominal Price Rigidity, Money Supply Endogeneity, and Business Cycles." *Journal of Monetary Economics,* 37(2): 345-370.

Appendix: The Linearized Phillips Curves

This Appendix derives the two Phillips curves (22) and (24) in the paper. Let's start by equation (22). Let $\tilde{w}_t$ be the deviation of the optimal relative wage from its steady state value, i.e., $\tilde{w}_t = w_t^* - w_t$, and let $\pi_{w,t+i} = w_{t+i} - w_{t+i-1}$. Linearizing the labor demand schedule (2), the aggregate wage level expression (8), and the optimal relative wage condition (6) about the steady state of the model, one obtains respectively

$$h_{i,t+\tau} = h_{t+\tau} - \theta_w(\tilde{w}_t + w_t - w_{t+\tau}), \tag{A.1}$$

$$\tilde{w}_t = \frac{\xi_w}{(1-\xi_w)}\pi_{w,t}, \tag{A.2}$$

$$\frac{1}{(1-\beta\xi_w)}\tilde{w}_t = E_t\sum_{\tau=0}^{\infty}(\beta\xi_w)^\tau\left[mrs_{i,t+\tau} - (w_{t+\tau} - p_{t+\tau}) + \sum_{\iota=1}^{\tau}\hat{\pi}_{w,t+\iota}\right]. \tag{A.3}$$

The marginal rate of substitution of the member i is given by

$$mrs_{i,t} = \psi_w h_{i,t} - \mathsf{h}_w h_{i,t-1} - \beta\mathsf{h}_w E_t h_{i,t+1} - \lambda_t, \tag{A.4}$$

where $\mathsf{h}_w = \eta\varphi/[(1-\varphi)(1-\beta\varphi)]$, and $\psi_w = \eta+(1+\beta)\mathsf{h}_w$. After substituting (A.1) in (A.4), one can express $mrs_{i,t}$ as a function of mrs_t

$$mrs_{i,t+\iota} = mrs_{t+\iota} - \theta_w\psi_w\left[\tilde{w}_t - E_t\sum_{\iota=1}^{\tau}\pi_{w,t+\iota}\right] + \mathsf{h}_w\left[\tilde{w}_{t-1} - E_t\sum_{\iota=1}^{\tau-1}\pi_{w,t+\iota-1}\right] + \beta\mathsf{h}_w E_t\left[\tilde{w}_{t+1} - \sum_{\iota=1}^{\tau+1}\pi_{w,t+\iota+1}\right]. \tag{A.5}$$

Substituting (A.2) and (A.5) in (A.3), and rearranging, I obtain the wage-Phillips curve (22) in the paper.

I now derive the price-Phillips curve (24) in the paper. The derivation follows the same steps as the one presented above. Let $\tilde{p}_t$ be the deviation of the optimal relative price from its steady state value, i.e., $\tilde{p}_t = p_t^* - p_t$, and let $\pi_{t+\iota} = p_{t+\iota} - p_{t+\iota-1}$. Linearizing the demand for intermediate good j (10), the aggregate price index expression (17), and the optimal relative price condition (16) about the steady state of the model, one obtains respectively

$$y_{j,t+\tau} = y_{t+\tau} - \theta_p(\tilde{p}_t + p_t - p_{t+\tau}), \tag{A.6}$$

$$\tilde{p}_t = \frac{\xi_p}{(1-\xi_p)}\pi_t, \tag{A.7}$$

$$\frac{1}{(1-\beta\xi_p)}\tilde{p}_t = E_t\sum_{\tau=0}^{\infty}(\beta\xi_p)^\tau\left[mc_{j,t+\tau} + \sum_{\iota=1}^{\tau}\hat{\pi}_{t+\iota}\right]. \tag{A.8}$$

Using the fact that $h_{j,t} = y_{j,t}$, the real marginal cost of firm j can be written as

$$mc_{j,t} - p_t = \eta y_{j,t} - \lambda_t + \Psi''(1)(y_{j,t} - y_{j,t-1}) - \beta\Psi''(1)(E_t y_{j,t+1} - y_{j,t}). \tag{A.9}$$

Making use of (A.6) and (A.9), $mc_{j,t}$ can be expressed as a function of mc_t

$$mc_{j,t+\iota} - p_{t+\iota} = mc_{t+\iota} - p_{t+\iota} - \theta_p\psi_p\left[\tilde{p}_t - E_t\sum_{\iota=1}^{\tau}\pi_{t+\iota}\right] + \mathsf{h}_p\left[\tilde{p}_{t-1} - E_t\sum_{\iota=1}^{\tau-1}\pi_{t+\iota-1}\right] + \beta\mathsf{h}_p E_t\left[\tilde{p}_{t+1} - \sum_{\iota=1}^{\tau+1}\pi_{t+\iota+1}\right], \tag{A.10}$$

where $\mathsf{h}_p = \Psi''(1)$, and $\psi_p = \eta+(1+\beta)\mathsf{h}_p$. Substituting (A.7) and (A.10) in (A.8), and rearranging, I obtain the price-Phillips curve (24) in the paper.

Assume now that we relax the assumption that labor is firm specific. An implication of the presence of labor adjustment costs is that the real marginal cost of firm j is no longer equal to the aggregate real marginal cost. The price-Phillips curve in this case has exactly the same form as equation (24). The only difference between the two equations lies in the definition of ψ_p. With integrated labor markets, ψ_p is replaced by $\psi'_p = (1+\beta)\Psi''(1)$. The effect of labor specificities is taken into account through the term η in ψ_p. Notice that $\psi'_p < \psi_p$, implying that one can obtain more sluggishness in inflation and thereby larger real effects of monetary shocks in a sticky-price model including labor adjustment costs if labor is considered as firm specific.