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The New Keynesian Phillips Curve and Staggered Price and Wage Determination in a Model with Firm-Specific Labor*

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Abstract

We develop a DSGE model with firm-specific labor where wage and price setting are subject to Calvo-type staggering. This is in general an intractable problem due to complicated intertemporal dependencies between price and wage decisions. However, the problem is significantly simplified if we, in line with empirical evidence, assume that prices can be changed whenever wages are. We show that the price- and wage-setting relationships are substantially altered by the introduction of firm-specific labor. Specifically, the inflation response is substantially dampened, whereas the wage inflation response is increased as compared to models with freely mobile labor. These distinctive features of the model with firm-specific labor are supported by empirical evidence from a structural VAR.

Keywords: Monetary Policy, Inflation Persistence, Labor Market, Strategic Complementarity.

JEL classification: E52, E58, J41.

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1 Introduction

In a growing literature, a number of papers have studied the role of firm-specific factors in generating strategic complementarity and thus a dampened response of inflation to shocks in New Keynesian models without requiring an implausible degree of nominal staggering. One strand of this literature has worked on the implications of firm-specific labor, see e.g. Woodford (2003), whereas another strand has focused on effects of firm-specific capital, see e.g. Sbordone (2002), Woodford (2003, 2005), Sveen and Weinke (2004), Altig, Christiano, Eichenbaum, and Linde (2010). Recently, models of the labor market have also been incorporated in New Keynesian DSGE models with *both* sticky prices and wages, see e.g., Erceg, Henderson, and Levin (2000) (EHL), Gertler, Sala, and Trigari (2008) and others. However, these models rely on simplifying assumptions to avoid complicated, but potentially important, dependencies between price- and wage-setting decisions. One approach, taken by e.g. Gertler, Sala, and Trigari (2008), is to separate price and wage setting into different sectors. Alternatively, as in the EHL framework, these interdependencies are removed by assuming that each worker posts a wage, common for all firms, and works an infinitesimal amount at each firm, implying that the price in a given firm does not affect the wage set by a worker and vice versa.¹

The purpose of this paper is to outline a model with firm-specific labor that incorporates both staggered prices and wages in the same sector. Using the model, we study the consequences for price and wage setting, as well as for equilibrium dynamics and optimal monetary-policy choices. We also evaluate the model's empirical merits, relative to models with freely mobile labor, in terms of matching estimated impulse-response functions from a structural vector autoregressive (SVAR) model.

Introducing both Calvo-type staggered prices and wages when wages are set within the firm is complicated, since there will be a dependence between current and future price/wage decisions. If a firm changes the price today, profits are affected today and in the future. This in turn affects future wage setting via the firm's future surpluses. Since wages will be different, marginal cost is also affected, leading to changes in future optimal prices. Thus, under firm-specific wage setting, price decisions and, by a similar argument, wage decisions cannot be analyzed by the simple methods in the standard Calvo framework where current decisions are independent of future and past decisions. This interdependency problem will be a feature of *all* models with both goods and labor markets where staggered price and wage determination occurs in the same sector, see e.g. Kuester (2010).²

We assume that a worker works at a specific firm and that wage setting is firm-specific, thus generating the interdependency problem discussed above. However, we show that this problem can be

¹See e.g. Smets and Wouters (2003), Altig, Christiano, Eichenbaum, and Linde (2010), Christiano, Eichenbaum, and Evans (2005), Adolfson, Laséen, Lindé, and Villani (2008) and others.

²Note that the price- and wage-setting model of Kuester (2010) is a non-generic special case of the model presented here.

solved in a straightforward way by slightly modifying the standard Calvo contracts. Similar to Calvo (1983), wage setting is opened with some fixed probability in each period. Price setting is slightly different from Calvo (1983). Specifically, if wages change at a given firm, prices are also allowed to change. Firms where wages are not changed are selected with some fixed probability to change prices, as in Calvo (1983). As discussed below, this modification is in line with the micro evidence. The key aspect of this assumption is that it greatly simplifies our problem. It particularly eliminates the interdependence between current and future prices. Similarly, the interdependence between current and future wage contracts is also eliminated.

Although workers set wages as in EHL, the wage-setting relationship in our model is substantially altered in comparison to the EHL framework. Notably, due to the reduced competition between workers on the labor market when labor is firm-specific, there is a much stronger direct effect between productivity (or any other factor affecting the surplus) and wage inflation in the wage-setting curve. Also, the price-setting curve (i.e. the New Keynesian Phillips Curve) is affected by the introduction of the firm-specific elements above. Specifically, price-setting will be directly affected by wage inflation.

We compare a set of three models: The EHL model, the EHL model with firm-specific capital (FSC) and the model derived in this paper featuring both firm-specific capital and labor (FSL/FSC). In our baseline calibration, we find that introducing firm-specific labor gives rise to an additional flattening of the New Keynesian Phillips Curve as compared to the case with freely mobile labor. This, in turn, leads to a much smaller inflation response in the FSL/FSC model than in the FSC (and the EHL) model.³ This is due to a much larger wage-inflation response in the model with firm-specific labor. The reason why inflation responds much less to e.g. a productivity shock with firm-specific labor is that the worker in the FSL/FSC model recognizes that wage choices also govern labor demand *indirectly* via price-setting. In case productivity increases, and prices and wages change, labor demand and the marginal disutility of supplying labor increases. With firm-specific labor, workers then have an additional channel to affect the marginal disutility of labor supply. Specifically, when increasing the wage, labor demand is reduced; first, directly by moving along the labor demand curve and, second, indirectly in the FSL/FSC model, by shifting the labor-demand curve through the effect of wage changes on prices. Note also that competition between workers in the FSL/FSC model works indirectly via the product market. Because labor-market competition is substantially mitigated in the baseline FSL/FSC model, the total counteracting wage increase is fairly large, in turn reducing the effect on the desired production level and prices from a productivity increase. Hence, in the Kimball (1995) sense, inflation responds little to productivity due to this ω -type strategic complementarity.

³This holds irrespectively if policy is governed by a Taylor (1993) type rule with interest-rate smoothing or if it is optimally chosen.

We find that the dampened inflation response, as well as the stronger response of wage inflation in the FSL/FSC model, is supported by the data. Specifically, we compare the theoretical impulse responses of inflation and wage inflation to a productivity shock derived using a Taylor (1993)-type rule with interest-rate smoothing to those obtained from a SVAR, identifying productivity shocks using long-run restrictions as in Galí (1999). We find that the FSL/FSC model matches the point estimate of the empirical inflation response very well. Moreover, the model also matches the initial empirical wage-inflation response, although it predicts a little too much persistence in the intermediate term. In contrast, both the EHL model and the FSC model imply too much inflation volatility and the inflation impulse responses are initially well outside the 90-percent confidence bands of the SVAR responses. Moreover, the EHL and the FSC models predict a much smaller initial response of wage inflation than implied by the point estimate of the SVAR. However, the wage-inflation responses of both the EHL and FSC models stay within the confidence bands of the empirical impulse response function.

Further, we find that allowing for non-synchronized wage and price setting has important effects on the inflation response. In particular, when price and wage changes are completely synchronized, as in Kuester (2010), price-setting behavior is very much altered compared to our baseline calibration and inflation hardly responds at all to productivity shocks. This stems from that equilibrium marginal cost is almost unchanged due to the wage response to the productivity shock.

When deriving a model-consistent welfare measure in terms of a second-order approximation of the social welfare function, we find that the main effect of introducing firm-specific labor is that the loss associated with inflation variability increases dramatically. This is because price dispersion leads to variation in labor supply between households since they are attached to a given firm in the FSL/FSC framework.

Across all three models, optimal policy is characterized by similar responses for inflation and wage inflation as compared to a simple Taylor (1993)-type rule with interest-rate smoothing. However, optimal policy implies a much more aggressive response of the interest rate in all models as compared to the simple rule.

This paper is closely related to a number of papers that study the effects of firm-specific factors on equilibrium dynamics. Several papers have focused on the effect of firm-specific capital on the New Keynesian Phillips Curve; see Sbordone (2002), Woodford (2003, 2005), Sveen and Weinke (2004), Altig, Christiano, Eichenbaum, and Linde (2010). Overall, firm-specific capital flattens the New Keynesian Phillips Curve via ω -type strategic complementarity, allowing for a better fit with empirical observations. The mechanism works by steepening the marginal-cost curve through (temporarily) decreasing returns to scale, which then lowers the desired price change in response to shocks. In a

related paper Woodford (2003) also studies a model with fixed capital, as well as firm-specific labor (but with flexible wages), where again the mechanism for flattening the New Keynesian Phillips Curve works via decreasing returns.⁴ Furthermore, Thomas (2007) analyzes a model where firm-specific labor, due to search and matching frictions, gives rise to a strategic complementarity mechanism related to our model, and finds a more muted effect of productivity shocks on desired price changes. The key difference is that we introduce staggered wage contracts, which is important to match observed wage contract duration as well as wage dynamics, whereas wages are flexible in the Thomas (2007) model.

In section 2 we outline the model. Sections 3 and 4 describe the market clearing conditions and derive a quadratic expression for the social welfare function, respectively. In section 5, we describe the monetary policy regimes we consider. Section 6 discusses the baseline calibration. Section 7 reports our numerical findings as well as the empirical SVAR evidence. Finally, section 8 concludes.

2 The Economic Environment

The model outlined below is in many respects similar to the model in EHL and others. Goods are produced by monopolistically competitive producers using capital and labor. Producers set prices in staggered contracts as in Calvo (1983). There are also some important differences due to the introduction of firm-specific labor. First, in order to introduce complete consumption insurance we rely on a representative family as in Merz (1995) that consists of a large number of households. Moreover, a household is attached to a specific firm.⁵ Thus, firms do not perceive workers as atomistic. In each period, wage adjustment at a specific firm takes place with a fixed probability. Accordingly, wages are staggered as in Calvo (1983) and determined unilaterally by the worker as in EHL. Moreover, given the wage, the firm decides upon employment each period as in EHL. The household derives utility from consumption, real balances and leisure, earning income by working at a specific firm and from capital holdings. Below, we present the model in more detail and derive key relationships (see the accompanying technical appendix Carlsson and Westermarck, 2008, for a full derivation).

2.1 Price and Wage Setting with Firm-Specific Labor

Firm-specific wage setting and staggered price and wage contracts implies that there is a potential interdependence between wage and price choices. The reason is that the firm price affects both firm profits and labor demand and hence, workers' payoff. This, in turn, affects the optimal wage. An

⁴Thus, one can also think of this model as a model with firm-specific capital, see Woodford (2003) p. 148.

⁵There is thus no reallocation of workers among firms. This is similar to Woodford (2003) ch. 3 and obviously a simplifying assumption, but it enables us to describe the model in terms of reasonably simple relationships.

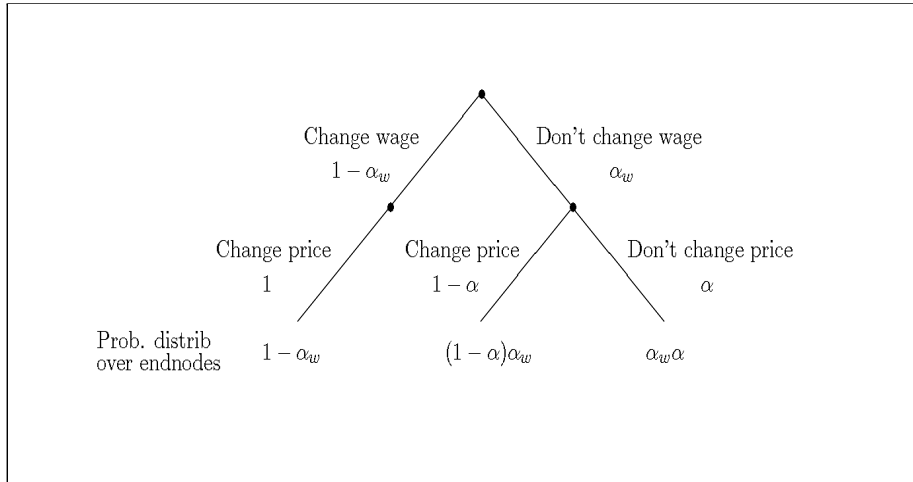


Figure 1: Timing of wage and price setting in a given period.

important implication of this is that there may be a relationship between wage setting today and in the future. The reason is that the wage set today affects prices set in the future which, in turn, act as a state variable in future wage decisions. Similarly, there is a potential relationship between current and future price setting through wages. Such interdependence would make the analysis of wages and prices much more complicated.

These interdependencies are not present in e.g. EHL, where households work an infinitesimal amount in each firm and hence are unaffected by price decisions in individual firms, implying that local prices do not affect wage decisions. Moreover, individual wages in a specific household do not affect price setting in firms by a similar argument.⁶

To avoid the interdependence problem, we assume that whenever wages are changed, prices are also adjusted. Specifically, this assumption ensures that there is no interdependence between current and future wage setting, since the only channel that could cause this – a price that is valid for two different wage contracts – is ruled out. Although intertemporal interdependencies between current and future wage contracts are eliminated, we still need to keep in mind that the current wage contract affects current and future price decisions. The timing assumption in wage and price setting is illustrated in figure 1.

Moreover, the assumption is also in line with the micro evidence on price-setting behavior presented in Altissimo, Ehrmann, and Smets (2006) where price and wage changes seem to be synchronized in time to a non-negligible extent (see especially figure 4.4, which in turn draws on work by Stahl, 2005). Here, we assume that wage changes induce price changes, since assuming the reverse would imply that

⁶These interdependencies are neither present in sticky price and wage models where prices and wages are set in different sectors, like in Gertler, Sala, and Trigari (2008) and others.

the duration of wage contracts could never be longer than for prices, which is empirically implausible (see section 6). Furthermore, since intertemporal interdependencies are eliminated, this allows us to describe the goods-market equilibrium by a similar but not identical type of forward looking New Keynesian Phillips curve as in EHL (see expression (18) below). Note that the model rules out the case when firms adjust wages but not prices. Since this case have zero price changes, it is plausible to believe that our model provides an upper bound to the inflation response.

When introducing search frictions into a New Keynesian model with both staggered price- and wage-setting in the same sector, Kuester (2010) runs into the same interdependency problem since these frictions render workers (temporarily) firm specific. Kuester (2010) solves this problem by assuming that price and wage setting are completely synchronized. This is, of course, a special (non-generic) case of the solution proposed here. As we will see below, complete synchronization of wage and price decisions have large effects on equilibrium dynamics.

2.2 Firms and Price Setting

Since households will be identical, except for leisure choices, it simplifies the analysis to abstract away from the households' optimal choices for individual goods. Thus, we follow the literature and assume a competitive sector selling a composite final good. The composite good is combined from intermediate goods in the same proportions as those that households would choose. The composite good is, assuming a continuum of firms, defined on the unit interval,

$$Y_t = \left[\int_0^1 Y_t(f)^{\frac{\sigma-1}{\sigma}} df \right]^{\frac{\sigma}{\sigma-1}}, \quad (1)$$

where $\sigma > 1$ and $Y_t(f)$ is the intermediate good produced by firm f . The price P_t of one unit of the composite good is set equal to the marginal cost

$$P_t = \left[\int_0^1 P_t(f)^{1-\sigma} df \right]^{\frac{1}{1-\sigma}}. \quad (2)$$

By standard arguments, the demand function for the intermediate good f is

$$Y_t(f) = \left(\frac{P_t(f)}{P_t} \right)^{-\sigma} Y_t. \quad (3)$$

The production of firm f in period t , $Y_t(f)$, is given by the following technology

$$Y_t(f) = A_t L_t(f)^{1-\gamma}, \quad (4)$$

where A_t is the technology level common to all firms and $L_t(f)$ denote the firms' labor input in period t . Since firms decide upon employment, $L_t(f)$ is chosen optimally, taking the bargained wage $W_t(f)$ as given. Note that the model can be thought of as a model with firm-specific capital, where the capital stock is fixed and cannot be adjusted, see Woodford (2003).⁷ Standard cost-minimization arguments then imply that the marginal cost in production is given by

$$MC_t(f) = \frac{W_t(f)}{MPL_t(f)}, \quad (5)$$

where $MPL_t(f)$ is the firm's marginal product of labor.

2.2.1 Prices

Given that wages are unchanged, the firm is allowed to change prices in a given period with probability $1 - \alpha$. Wages are reset with probability $1 - \alpha_w$. As mentioned above, any firm where wages change can also change prices. Thus, the probability that a firm's price is unchanged is $\alpha_w \alpha$. The producers choose prices to maximize

$$\begin{aligned} \max_{p_t(f)} E_t \sum_{k=0}^{\infty} (\alpha_w \alpha)^k \Psi_{t,t+k} [(1 + \tau) P_t(f) Y_{t+k}(f) - TC(W_{t+k}(f), Y_{t+k}(f))] \quad (6) \\ \text{s. t. } Y_{t+k}(f) = \left(\frac{P_t(f)}{P_{t+k}} \right)^{-\sigma} Y_{t+k}, \end{aligned}$$

where $TC(W_{t+k}(f), y_{t+k}(f))$ denotes the cost function, $\Psi_{t,t+k}$ is the households' valuation of (nominal) profits in period $t+k$ when in period t and τ is a tax/subsidy on output. The term inside the square brackets is firm profits in period $t+k$, given that prices are last reset in period t . The first-order condition is

$$E_t \sum_{k=0}^{\infty} (\alpha_w \alpha)^k \Psi_{t,t+k} \left[\frac{\sigma - 1}{\sigma} (1 + \tau) P_t(f) - MC_{t+k}(f) \right] Y_{t+k}(f) = 0. \quad (7)$$

The subsidy τ is determined so as to set $\frac{\sigma - 1}{\sigma} (1 + \tau) = 1$. That is, we assume that fiscal policy is used to alleviate distortions due to monopoly price setting.

2.3 Households

In the economy, there is a representative family that consists of a continuum of households. Moreover, each household is linked to a local labor market with a single firm f . Each household, in turn,

⁷Allowing for capital accumulation in the firm would lead to complicated interdependencies between current and future price and wage decisions. Unfortunately, the approach in Woodford (2005) cannot be used since the wage and capital stock would be chosen to maximize different objective functions.

has a continuum of members where a fraction is employed by the firm in the local labor market. Since the family pools income across households, the households are homogeneous with respect to consumption and real money balances. Thus, in other words, the family provides income insurance for their households which, in turn, may differ in the fraction of household members that are employed and in the wage received due to the labor market conditions at the local labor market.

The expected life-time utility of the family in period t is given by⁸

$$E_t \left\{ \sum_{s=t}^{\infty} \beta^{s-t} \left[u(C_s) + l \left(\frac{M_s}{P_s} \right) - \int_0^1 \left(\int_0^{L_s(f)} (v(H^e) + \vartheta(j)) dj \right) df - \int_0^1 \int_{L_s(f)}^1 v(0) dj df \right] \right\}, \quad (8)$$

where $\beta \in (0, 1)$ is the household's discount factor and $L_s(f)$ is the fraction of employed members of the household attached to firm f . Here, C_s is final goods consumption in period s , M_s/P_s is real money balances, where M_s denotes money holdings, and $v(H^e)$ and $v(0)$ the disutility of being employed and unemployed, respectively. Thus, average hours per employee are constant and equal to H^e . Moreover, there is a distribution over the disutility of supplying labor, ϑ , for each household member (due to, e.g. the dislike and distance of commuting) where the household always allocates the member with the least cost to the labor market giving rise to the term $\vartheta(j)$.⁹ Thus, the firm faces an upward-sloping labor-supply function when renegotiating wages.

The budget constraint of the family is given by

$$\frac{B_t}{P_t I_t} + \frac{M_t}{P_t} + C_t = \frac{M_{t-1} + B_{t-1}}{P_t} + D_t, \quad (9)$$

where

$$D_t = (1 + \tau_w) \int_0^1 \frac{W_t(f) L_t(f)}{P_t} df + \left(1 - \int_0^1 L_t(f) df \right) b + \frac{\Gamma_t}{P_t} + \frac{T_t}{P_t}.$$

Here, I_t is the one period gross nominal interest rate and B_t denotes one period (nominal) bonds. Moreover, $W_t(h)$ denotes the household's nominal wage and τ_w is the tax rate (subsidy) on labor income. Each family owns an equal share of all firms and of the aggregate capital stock. Then, Γ_t is the family's aliquot share of profits and rental income. Also, T_t denotes nominal lump sum transfers

⁸In the Technical Appendix, we also introduce a consumption shock and a labor-supply shock as in EHL. Here, however, we only focus on technology shocks. This is due to that, under optimal policy, all disturbances in the model (introduced as in EHL) can be reduced to a single disturbance term (being a linear combination of all these shocks), thus not yielding any additional insights.

⁹An alternative interpretation is given in Cho and Cooley (1994). The interpretation (given the current setting) is then that, when unemployed, there is a household production opportunity available for the household member. There is a loss $\int_0^{L_s(f)} \vartheta(j) dj$ when a fraction $L_s(f)$ of the household members are employed. Due to decreasing returns in home production this loss is increasing in $L_s(f)$.

from the government. Finally, note that $\left(1 - \int_0^1 L_t(f) df\right)$ is equal to the unemployment rate and b is the real monetary payoff to unemployed workers.

2.4 Wage Setting

Wages are determined unilaterally by a union representing the household attached to firm f (in Appendix A we study the case with firm bargaining power). We start by denoting the value for the family of the household attached to firm f in period $t+k+j$, given that prices were last changed in $t+k$ and wages in t by $U_{t+k,t+k+j}^t$. Wages are determined by

$$\max_{W(f)} U_{t,t}^t. \quad (10)$$

Using the family payoff (8) and budget constraint (9), the value for the household attached to firm f is

$$-\frac{V(L_t(f))}{u_C(C_t, Q_t)} + \left((1 + \tau_w) \frac{W_t(f)}{P_t} L_t(f) - b(1 - L_t(f)) \right) \quad (11)$$

where

$$V(L_t(f)) = (L_s(f) v(H^e) + (1 - L_s(f)) v(0)) + \left(\int_0^{L_s(f)} \vartheta(j) dj \right). \quad (12)$$

To derive $U_{t,t}^t$ in (10), we let

$$\Upsilon_{t+k,t+k+j}^t = L_{t+k,t+k+j}^t(f) \left((1 + \tau_w) \frac{(\bar{\pi})^{k+j} W_t(f)}{P_{t+k+j}} \right) + (1 - L_{t+k,t+k+j}^t(f)) b \quad (13)$$

$$\frac{V(L_{t+k,t+k+j}^t(f), Z_{t+k+j})}{u_{C,t+k+j}}$$

denote per-period utility.¹⁰ Then we can write

$$U_{t,t}^t = \Upsilon_{t,t}^t + \alpha_w \beta E_t \frac{u_{C,t+1}}{u_{C,t}} (\alpha U_{t,t+1}^t + (1 - \alpha) U_{t+1,t+1}^t) + (1 - \alpha_w) \beta E_t \frac{u_{C,t+1}}{u_{C,t}} U_{t+1,t+1}^{t+1}. \quad (14)$$

In the next period, wages may or may not be adjusted. If wages are not changed, which happens with probability α_w , prices either change with probability $1 - \alpha$ giving value $U_{t+1,t+1}^t$ or they do not change giving value $U_{t,t+1}^t$. If wages are changed, happening with probability $1 - \alpha_w$, the value is $U_{t+1,t+1}^{t+1}$. The term $\beta E_t \frac{u_{C,t+1}}{u_{C,t}}$ represents discounting.

The first-order condition of (10) is

$$\frac{\partial U_{t,t}^t}{\partial W(f)} = 0. \quad (15)$$

¹⁰The derivation of this follows the lines of Trigari (2006) and that a worker at firm f is employed with probability $L_s(f)$ in period s .

Finally, τ_w is used to ensure that the marginal product of labor equates the marginal rate of substitution in the steady state, i.e. we eliminate distortions in wage setting.

2.5 Steady State

In the zero-inflation non-stochastic steady state, A_t is equal to its steady-state value, \bar{A} . Moreover, all firms produce the same (constant) amount of output, i.e. $\bar{Y}(f) = \bar{Y}$, using the same (constant) quantity of labor and all firms demand the same amount of labor, i.e. $\bar{L}(f) = \bar{L}$. Moreover, we will have that $\bar{C} = \bar{Y}$ and $B = 0$. Also, M and P are constant. Finally, note that under the tax-scheme outlined above that eliminates distortions, we will have that $\overline{MPL} = \overline{MRS}$.

3 Market Equilibrium Conditions

Since we eliminate the distortions in the economy (using τ and τ_w), it follows that it suffices to look at a linear-quadratic representation of the model to rank policies in term of welfare (see Woodford (2003) ch. 6 for a discussion). We proceed by log-linearizing the first-order conditions describing market behavior. First, let the superscript * denote variables in the flexible price and wage equilibrium, which we below refer to as the natural equilibrium, and a hat above a small letter variable denotes log-deviations from the variables steady-state level (except the output gap, \hat{x} , which is defined as the log-deviation between output and the natural output level). Log-linearizing around the steady state gives the following system of equations (see the technical appendix for details)

$$\hat{x}_t = E_t \left(\hat{x}_{t+1} - \frac{1}{\rho_C} (\hat{i}_t - \hat{\pi}_{t+1} - \hat{r}_t^*) \right), \quad (16)$$

$$\hat{w}_t = \hat{w}_{t-1} + \hat{\pi}_t^\omega - \hat{\pi}_t, \quad (17)$$

$$\hat{\pi}_t = \beta E_t \hat{\pi}_{t+1} + (1 - \gamma) (\hat{\pi}_t^\omega - \beta E_t \hat{\pi}_{t+1}^\omega) + \Pi (\hat{w}_t - \hat{w}_t^*) + \frac{\gamma}{1 - \gamma} \Pi \hat{x}_t, \quad (18)$$

$$\hat{\pi}_t^\omega = \beta E_t \hat{\pi}_{t+1}^\omega - \Omega_x \hat{x}_t - \Omega_w (\hat{w}_t - \hat{w}_t^*), \quad (19)$$

where $1/\rho_C$ is the intertemporal elasticity of substitution in consumption and Ω_x and Ω_w are defined in appendix B and

$$\Pi = (1 - \alpha_w \alpha \beta) \frac{1 - \alpha_w \alpha}{\alpha_w \alpha} \frac{1 - \gamma}{1 - \gamma + \sigma \gamma}. \quad (20)$$

Equation (16) is the standard goods-demand equation which relates the output gap \hat{x}_t to the expected future output gap and the expected real interest-rate gap $(\hat{i}_t - \hat{\pi}_{t+1} - \hat{r}_t^*)$, where \hat{i}_t denotes the log-deviation of the nominal interest rate from steady state and \hat{r}_t^* is the log-deviation of the natural real interest rate from its steady state. This relation is derived using the household's first-

order condition with respect to consumption, i.e. the consumption Euler equation.

The evolution for the real wage follows from the definition of the aggregate real wage and is described by the identity (17), which states that today's real wage is equal to yesterday's real wage plus the difference between wage and price inflation ($\hat{\pi}_t^\omega - \hat{\pi}_t$).

3.1 Effects of Firm-Specific Labor

Both the Euler equation (16) and the evolution of real wages (17) are identical to the comparable expressions in the EHL model. In contrast, the price- and wage-setting decisions are affected by the introduction of firm-specific labor.

The price-setting (New Keynesian Phillips) curve, equation (18) is derived from the firm's first-order condition (7). In our model, the real wage driving inflation is different from the average economy-wide real wage, \hat{w}_t . This is due to the dependence between the probability of changing prices and wages. Specifically, since all firms that are allowed to change wages are also allowed to change prices, the share of firms where wages change among the firms that change prices is different from the economy-wide average, which then motivates the "correction term", $(1 - \gamma) (\hat{\pi}_t^\omega - \beta E_t \hat{\pi}_{t+1}^\omega)$. Thus, the real-wage effect in (18) has been decomposed into an aggregate real-wage change ($\hat{w}_t - \hat{w}_t^*$) effect and a wage-inflation ($\hat{\pi}_t^\omega - \beta E_t \hat{\pi}_{t+1}^\omega$) effect.¹¹

Equation (19) is the wage-setting curve. This expression is similar but not identical to the wage-setting relationship in the EHL and FSC models. Specifically, in the EHL and FSC models the $\hat{\pi}_t^\omega$ equation has different values for Ω_x and Ω_w .¹²

Firm-Specific Labor and the Inflation and Wage-Inflation Responses to Shocks

To see that firm-specific labor can lead to a flattening of the Phillips Curve, note that, in the FSC model, the Phillips Curve is

$$\hat{\pi}_t = \beta E_t \hat{\pi}_{t+1} + \Pi (\hat{w}_t - \hat{w}_t^*) + \frac{\gamma}{1 - \gamma} \Pi \hat{x}_t \quad (21)$$

and, in the FSL/FSC model, eliminating the wage inflation terms in (18) by using (19), the Phillips Curve is

$$\hat{\pi}_t = \beta E_t \hat{\pi}_{t+1} + (\Pi - (1 - \gamma) \Omega_w) (\hat{w}_t - \hat{w}_t^*) + \left(\frac{\gamma}{1 - \gamma} \Pi - (1 - \gamma) \Omega_x \right) \hat{x}_t. \quad (22)$$

Thus, the responsiveness of inflation to shocks, i.e. innovations to \hat{w}_t^* , changes by $(1 - \gamma) \Omega_w$. This

¹¹ Note also that estimating a New Keynesian Phillips Curve without the correction term in the current setting would lead to omitted-variables bias (as would omitting the real-wage gap term).

¹² If $b = 0$ and the inverse of the Frisch labor supply elasticity, ρ_L , is equal to zero in both models, the wage-setting relationships coincide (c.f. the technical appendix).

is caused by the indirect effects via wage setting, where an increase in the real wage gap leads to changes in wage inflation.¹³ Using the baseline calibration presented in table 1 below, the coefficient in front of the real wage gap decreases substantially from 0.0762 to 0.0190. Thus, the introduction of firm-specific labor leads to a significant flattening of the Phillips Curve. The wage setting curve is also substantially modified. The responsiveness of wage inflation to shocks increases more than forty-fold from -0.00209 to -0.0858 .¹⁴ As we will see below, these effects remains qualitatively in a full-fledged general equilibrium analysis.

4 Welfare

Following the main part of the monetary-policy literature, we focus on the limiting cashless economy (see e.g. Woodford, 2003, for a discussion) with the social welfare function

$$E_t \sum_{t=0}^{\infty} \beta^t \left(u(C_t) - \int_0^1 V(L_t(h)) dh \right). \quad (23)$$

Proceeding as in Rotemberg and Woodford (1997), EHL and others, we take a second-order approximation to (23) around the steady state. This yields the following (standard) expression for the welfare gap (see the technical appendix), in terms of the discounted sum of per-period log-deviations of welfare from the natural (flexible price and wage) welfare level,

$$E_t \sum_{t=0}^{\infty} \beta^t \left(\theta_x (\hat{x}_t)^2 + \theta_{\pi} (\hat{\pi}_t)^2 + \theta_{\pi\omega} (\hat{\pi}_t^{\omega})^2 \right), \quad (24)$$

where we have omitted higher order terms and terms independent of policy and as usual $\theta_x < 0$, $\theta_{\pi} < 0$ and $\theta_{\pi\omega} < 0$ (see appendix B for definitions). The first term captures the welfare loss (relative to the flexible price and wage equilibrium) from output gap fluctuations stemming from the fact that \widehat{mpl}_t will differ from \widehat{mrs}_t whenever $\hat{x}_t \neq 0$. However, even if $\hat{x}_t = 0$, there will be welfare losses due to nominal rigidities. The reason is that nominal rigidities imply a non-degenerate distribution of prices and wages. Non-degenerate distributions of prices and wages imply non-degenerate distributions of output across firms and employment across households. This leads to welfare losses due to decreasing returns to scale and non-linear preferences over leisure.

¹³Note that we disregard indirect general equilibrium effects through the output gap in this section.

¹⁴In comparison to the EHL model, the coefficient in front of the real wage gap in the Phillips curve decreases significantly from 0.229 to 0.0190, whereas the coefficient in the wage-setting curve in the EHL model is the same as in the FSC model.

5 Monetary Policy

To close the model and describe the dynamic equilibrium of the model, we need to specify the behavior of monetary policy. We consider two types of monetary-policy behavior. First, we consider a non-optimally chosen simple instrument rule based on empirical evidence to highlight the differences between a model with and without firm-specific labor. Second, to see what characterizes optimal behavior with and without firm-specific labor, we study optimal monetary policy where the central bank is aiming at maximizing the model-consistent measure of welfare (24).

5.1 A Simple Instrument Rule

The simple instrument rule we chose is based on the Taylor (1993) rule, but extended to allow for interest-rate smoothing, which seems to be a prominent feature of actual behavior of central banks,

$$\hat{i}_t = (1 - \rho_I) (\gamma_\pi \hat{\pi}_t + \gamma_x \hat{x}_t) + \rho_I \hat{i}_{t-1}. \quad (25)$$

To close the general equilibrium system (16)-(19), we eliminate the nominal interest rate from the Euler equation (16) using the simple rule (25) and the real interest rate using the corresponding flexible-price Euler equation. This condition, together with the three constraints (17) to (19), describes the dynamic equilibrium of the model under the simple rule. The system can then be solved by standard methods (see Söderlind, 1999).

5.2 Optimal Policy

Under an optimal monetary policy regime, the central bank is assumed to maximize social welfare, as given by (24) subject to the restrictions (16)-(19). Note that welfare only depends on the paths of \hat{x}_t , $\hat{\pi}_t$ and $\hat{\pi}_t^\omega$. Moreover, these three variables can solely be determined by the first-order conditions from maximizing (24) and from the equations (17)-(19) and the shock process for \hat{w}_t^* . To solve for the commitment solution, we rewrite the system of constraints (17)-(19) and the shock process appropriately and then follow the method described in Söderlind (1999) (see the technical appendix for details).^{15,16}

¹⁵Note that we solve the problem in a different way than EHL. Instead of postulating the form of the interest rate rule and then choosing parameters to maximize welfare, we find the paths for \hat{x}_t , $\hat{\pi}_t$, $\hat{\pi}_t^\omega$ and \hat{w}_t that maximize welfare, as suggested by Woodford (2003).

¹⁶An alternative is to look at the timeless optimal policy (see Woodford, 2003). Note though, that the commitment policy, analyzed here, and the timeless policy will coincide if the model is initialized at the steady state (see Dennis, 2008, for a discussion).

6 Calibration and Numerical Solution

As in EHL, we only focus on a technology shock in our application, which is assumed to follow an AR(1) process. It is straightforward to show that there is a positive linear relationship between \hat{w}_t^* and \hat{A}_t . Then, if technology follows an AR(1) process, \hat{w}_t^* also follows an AR(1) process. We can thus model \hat{w}_t^* as

$$\hat{w}_t^* = \eta \hat{w}_{t-1}^* + \varepsilon_t, \quad (26)$$

where ε_t is an (scaled) i.i.d. (technology) shock with standard deviation σ_ε .

For our numerical exercises, we assume that

$$u(C_t) = \frac{1}{1 - \chi_C} (C_t - \bar{Q})^{1 - \chi_C}, \quad (27)$$

and that

$$v(H_t) = -\frac{1}{1 - \chi_L} (1 - H_t - \bar{Z})^{1 - \chi_L}, \quad (28)$$

where $H_t = \bar{H}$ is the amount of time workers work (where the maximum is normalized to unity). Here, we introduce \bar{Q} and \bar{Z} as in EHL.¹⁷ Moreover, we parametrize the disutility of labor supply as

$$\vartheta(j) = j^\varsigma. \quad (29)$$

The calibration of the deep parameters are presented in Table 1. To find the steady state of the model, we set the production technology parameter γ to 1/3, the employment rate \bar{L} to 0.95, $\bar{A} = 1$ and $\bar{H} = 0.27$, $\bar{Z} = 0.03$. Thus, \bar{H} and \bar{Z} stand for thirty percent of the household's time endowment. Then, to find the steady state, we use that $\overline{MPL} = \overline{MRS}$, which holds under the tax scheme outlined above, together with assumed values for the Frisch labor-supply elasticity, $1/\rho_L$, and the intertemporal elasticity of substitution in consumption, $1/\rho_C$.¹⁸ This then lets us determine χ_C , χ_L and ς , as well as all other steady state quantities in the model. Note that, in contrast to e.g. Smets and Wouters (2003), our model equalizes all interest-sensitive expenditures with non-durable consumption as in e.g. Boivin and Giannoni (2006). Thus, the intertemporal elasticity of consumption should be higher than unity in our model (as often used for non-durable consumption). Here we use a value of 0.2 for ρ_C , which is above the estimate of 0.08 reported by Boivin and Giannoni (2006) and slightly larger than the estimate of 0.16 reported by Rotemberg and Woodford (1997), but just below the estimate

¹⁷In the Technical Appendix we allow for consumption and labor supply shocks, but here they are held constant (see also the discussion in section 2.3). Moreover, \bar{Q} corresponds to the steady state value of a consumption shock and \bar{Z} to the steady state value of a labor-supply shock.

¹⁸The (inverse of the) Frisch labor-supply elasticity, ρ_L , is defined as $-\frac{V_{LL}\bar{L}}{V_L}$ and the (inverse of the) intertemporal elasticity of substitution in consumption, ρ_C , is defined as $-\frac{\bar{u}_{CC}\bar{C}}{\bar{u}_C}$.

of 0.23 reported by Giannoni and Woodford (2005).¹⁹ Moreover, we set ρ_L to -10 which is in line with the evidence collected by Card (1996) (and the value used by Trigari, 2006, and Kuester, 2007), while a bit lower than the estimate of 14.99 reported by Giannoni and Woodford (2005).²⁰ Letting d_p and d_w denote the duration of price and wage contracts, respectively, we have $d_p = 1/(1 - \alpha_w \alpha)$ and $d_w = 1/(1 - \alpha_w)$.

Table 1: Deep Parameters

α - Price adjustment	5/6	ρ_C - (Inverse of the) int. el. of subst.	0.2
α_w - Wage adjustment	3/4	ρ_L - (Inverse of the) Frisch el.	-10
β - Discount factor	0.99	η - Persistence in \hat{w}_t^*	0.95
γ - Technology parameter	1/3	σ_ϵ - Standard deviation of shock to \hat{w}_t^*	0.01
b/\bar{w} - Replacement rate	0.6	γ_π - Simple rule parameter for π_t	1.5
σ - CES price index parameter	4	γ_x - Simple rule parameter for x_t	0.5
σ_w - CES wage index parameter	4	ρ_I - Simple rule parameter for \hat{i}_{t-1}	0.8

Starting with wage contract duration, Taylor (1999) summarizes the evidence and argues that overall the evidence points toward a wage contract duration of about one year. A similar conclusion is drawn from the survey of the Wage Dynamics Network; see Fabiani, Galuscak, Kwapil, Lamo, and Rõõm (2010). This, in turn, implies that we set $\alpha_w = 3/4$. For price contract duration, the micro evidence presented by Nakamura and Steinsson (2008) and the survey evidence in Blinder, Canetti, Lebow, and Rudd (1998) suggests a contract duration of about eight months. This, in turn, implies that we set $\alpha = 5/6$. For, $\sigma (= 4)$, $\sigma_w (= 4)$ and $\eta (= 0.95)$ we follow EHL. For the replacement rate (b/\bar{w}) we use 0.6, which is about the 2004 net replacement rate during the initial phase of unemployment reported for the U.S. by the OECD. To calibrate the simple rule we use the parameters for $\gamma_\pi (= 1.5)$ and $\gamma_x (= 0.5)$ from Taylor (1993) and we set ρ_I equal to 0.8, which is consistent with the empirical literature.

Table 2: Derived Parameters

EHL		FSC		FSC/FSL	
Phillips curve					
Π	0.0762	Π	0.0762	Π	0.0762
Wage setting curve					
$\bar{\Pi}_W$	0.229	$\bar{\Pi}_W$	0.229	$\bar{\Pi}_W$	0.229
Ω_x^{EHL}	-0.0318	Ω_x^{FSC}	-0.0318	Ω_x	-0.0207
Ω_w^{EHL}	0.00209	Ω_w^{FSC}	0.00209	Ω_w	0.0858
Welfare					
θ_x^{EHL}	8.02	θ_x^{FSC}	8.02	θ_x	8.02
θ_π^{EHL}	8.932	θ_π^{FSC}	26.8	θ_π	562.7
$\theta_{\pi\omega}^{EHL}$	650.6	$\theta_{\pi\omega}^{FSC}$	650.6	$\theta_{\pi\omega}$	936.9

¹⁹This is the estimate for their model without habit persistence.

²⁰The values ρ_C and ρ_L imply values of $\chi_C = 0.537$, $\chi_L = 1.5$ and $\varsigma = 20.07$.

In table 2, we present the values of the derived coefficients for price- and wage-setting behavior. The coefficient in front of the real-wage gap in the EHL and the FSC framework (i.e. Ω_w^{EHL} and Ω_w^{FSC} , respectively) is almost zero, thus muting any of the (direct) wage-inflationary pressure from the real wage gap. The reason for this is the much stronger competition between households on the labor market in the model with freely mobile labor.²¹ Since some households do not change wages, a wage increase has a large negative effect on the labor demand faced by a wage-changing household leading to a small response of wage inflation. However, the coefficients in front of the output gap remain fairly similar across models (Ω_x , Ω_x^{EHL} and Ω_x^{FSC} , respectively).

Not only private-sector behavior is modified, though, when introducing firm-specific labor. The loss function also changes. As can be seen in table 2, the loss associated with inflation and wage inflation variability is by an order of magnitude larger than the loss associated with output-gap variability. With freely mobile labor (as in the EHL and FSC models), the cost of wage inflation variability is also large, whereas the cost of inflation variability is substantially smaller by a factor of at least 20, both with and without firm-specific capital. The reason why price dispersion is much more costly with firm-specific labor is that, with freely mobile labor, price dispersion does not give rise to dispersion in labor supply across households in contrast to the model with firm-specific labor.

7 Results

To highlight the effects of firm-specific labor, we first compare our model with the EHL and FSC models under the simple rule (25) and plot impulse responses relying on the baseline calibration above. Specifically, we impose the same Frisch labor-supply elasticity as well as the same expected price- and wage-contract duration across models for comparability. Moreover, we also compare these impulse responses to the empirical impulse responses obtained from a structural VAR. Finally, we analyze the consequences of optimal policy in the models.

7.1 Impulse Responses Under the Simple Rule

In Figure 2, we plot the impulse response to a one-percent innovation to the natural real wage \hat{w}_t^* when monetary policy is governed by the simple rule (25).

In all models, the shock initially drives up the natural real wage by one percent and thus causes a negative real-wage gap. To close the gap and stabilize the economy, the central bank needs to adjust the policy rate in order to increase the real wage. This is achieved by keeping inflation lower than wage inflation, which is also what the simple rule implies. However, given the AR(1) structure of the

²¹In the model with firm-specific labor, labor attached to different firms competes indirectly via the product market. Thus goods-market competition affects the coefficients in the wage-setting curve.

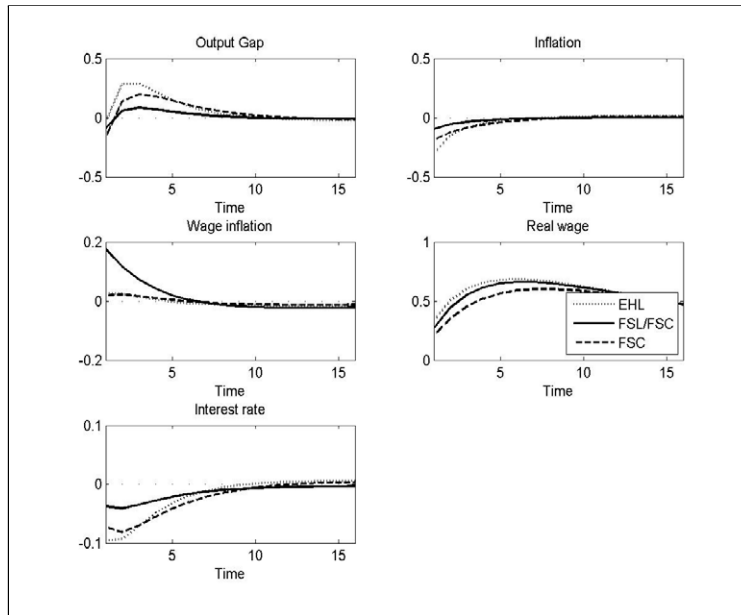


Figure 2: Impulse responses to a one-percent innovation to \hat{w}_t^* when the nominal interest rate is governed by the simple rule.

shock, the natural real wage falls down towards the steady value of zero after the initial shock. So at some point, the central bank needs to start to reduce the real wage in order to continue to stabilize the economy. This is also what we see after approximately six quarters. For this purpose, the relation between wage inflation and inflation ($\hat{\pi}_t^w - \hat{\pi}_t$) needs to be reversed, which also happens at this point in time. The economy is then stabilized and eventually tends towards the steady state.

Effects of Firm-Specific Labor

When comparing the impulse responses in figure 2, we see that the wage-inflation response is substantially higher in the model with firm-specific labor. As can also be seen in figure 2, the initial inflation response is almost doubled in the FSC model and tripled in the EHL model as compared to the model with firm-specific capital and labor. To see the intuition behind the effect of firm-specific capital, note that this feature introduces decreasing returns to scale and an upward-sloping marginal cost curve, in turn muting the response of the desired price to changes in productivity. The difference between the FSC and the FSL/FSC models stems from a slightly different mechanism. Firm-specificity in labor gives rise to dependence between wage and price/production decisions. Specifically, the worker in the FSL/FSC model recognizes that wage choices also govern labor demand *indirectly* via price setting. If productivity increases, and prices and wages change, labor demand and the marginal disutility of supplying labor increases. With firm-specific labor, workers have an additional

channel to affect the marginal disutility of labor supply. Specifically, when increasing the wage, labor demand is reduced through two channels. First, directly, by moving along the labor demand curve. Second, indirectly in the FSL/FSC model, by shifting the labor-demand curve through the effect of wage changes on prices. Note also that competition between workers in the FSL/FSC model works indirectly via the product market. Because labor-market competition is substantially mitigated in the baseline FSL/FSC model, the total counteracting wage increase is fairly large, which in turn reduces the effect on the desired production level and prices from a productivity increase. Thus, in the terminology of Kimball (1995), both firm-specific capital and firm-specific labor gives rise to ω -type strategic complementarity. The key underlying feature of our proposed form of ω -type strategic complementarity, in contrast to firm-specific capital, is that wages should react to firm-specific factors. Interestingly, recent work on the effect of firm-level idiosyncratic technology shocks on individual wages using matched employer-employee data support that this is the case; see Carlsson, Messina, and Nordström Skans (2009).

Using the Euler equation and the flexible price equilibrium, we can solve for the path of the equilibrium interest rate. As can be seen in figure 2, the policy rate initially decreases in all models in order to stabilize the economy, although much less in the model with firm-specific labor.

Effects of Synchronization between Price and Wage Setting

The degree of synchronization between price and wage decisions is of crucial importance for the inflation response, as can be seen from figure 3. When setting $\alpha = 1$, i.e. implying that price and wage decisions are perfectly synchronized and hence have the same expected contract duration as in Kuester (2010), inflation hardly responds at all to shocks (a substantially dampened response to inflation is also obtained under optimal policy and perfect synchronization, see section 7.4).²² This indicates that allowing for imperfect synchronization between price and wage decisions is important when studying effects of firm-specific labor. Inflation responds much more to a productivity increase (driving up the flexible-price real wage \hat{w}_t^*) when price and wages are not fully synchronized because some firms only change prices. When both wages and prices are changed in a firm, a productivity increase leads to an increase in wages. This, in turn, counteracts the downward pressure on prices of the productivity increase that works through the direct effect on marginal costs, leading to a small net effect of productivity on prices. Hence, if prices and wages are fully synchronized, the inflation response to productivity is small. In contrast, when there are firms that adjust only prices, the productivity effect through marginal costs has a large effect on prices since wages are unchanged, leading to a larger

²²See also the discussion of firm-specific labor in Christoffel, Costain, de Walque, Kuester, Linzert, Millard, and Pierrard (2009). Note that if we set the wage (price) duration to six (four) quarters as in the baseline calibration of Christoffel et al. (2009) the impulse responses remain similar to our baseline calibration.

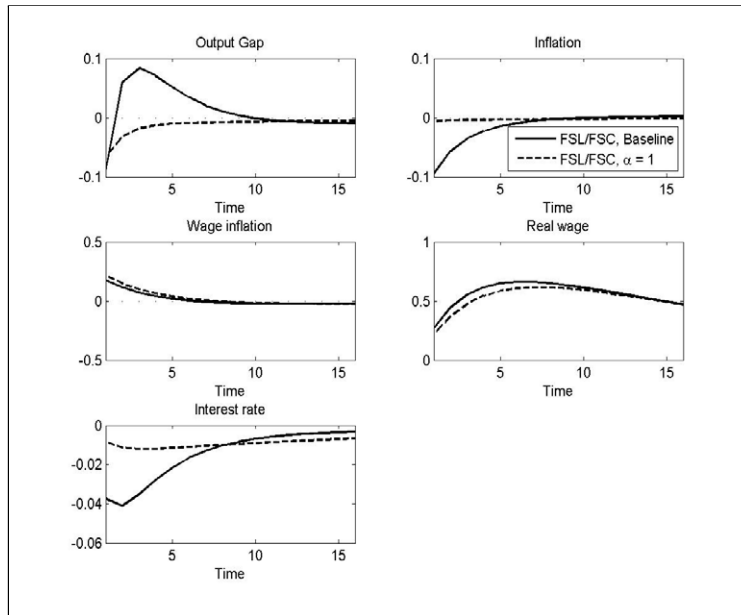


Figure 3: Impulse responses to a one-percent innovation to \hat{w}_t^* when the nominal interest rate is governed by the simple rule when $\alpha = 5/6$ and $\alpha = 1$, respectively.

negative response in inflation to a positive productivity shock.

7.2 Empirical Impulse Responses

In this section we provide a simple empirical evaluation of the models' predictions in the inflation/wage-inflation dimensions along the lines of Liu and Phaneuf (2007). That is, we compare the theoretical impulse responses from the models under the simple rule described in section 7.1 to the empirical impulse responses obtained using a SVAR approach. To this end, we estimate a four variable SVAR model with four lags including the growth rate of average labor productivity, the growth rate of per capita hours, price inflation and nominal wage inflation.^{23,24} The data are taken from the FRED database maintained by the Federal Reserve Bank of St. Louis. The average labor productivity series is output per hour of all persons for the nonfarm business sector (with series identifier *OPHNFB* in FRED). The hours per capita series is the hours of all persons in the nonfarm business sector (*HOANBS*) divided by the civilian non-institutional population 16 years and over (*CNP16OV*). The nominal price series is the consumer price index for all urban consumers (all items) (*CPIAUCSL*). The nominal wage series is compensation per hour in the nonfarm business sector (*COMPNFB*). To

²³Here we use the Structural VAR package version 0.45 release 2 coded by Anders Warne.

²⁴Alternatively, we could have modeled the hours series in levels as in Christiano, Eichenbaum, and Vigfusson (2004). Though, as argued by Fernald (2007), SVARs with long-run restrictions are extraordinarily sensitive to low frequency variation in the hours data. Hence, the use of a difference specification.

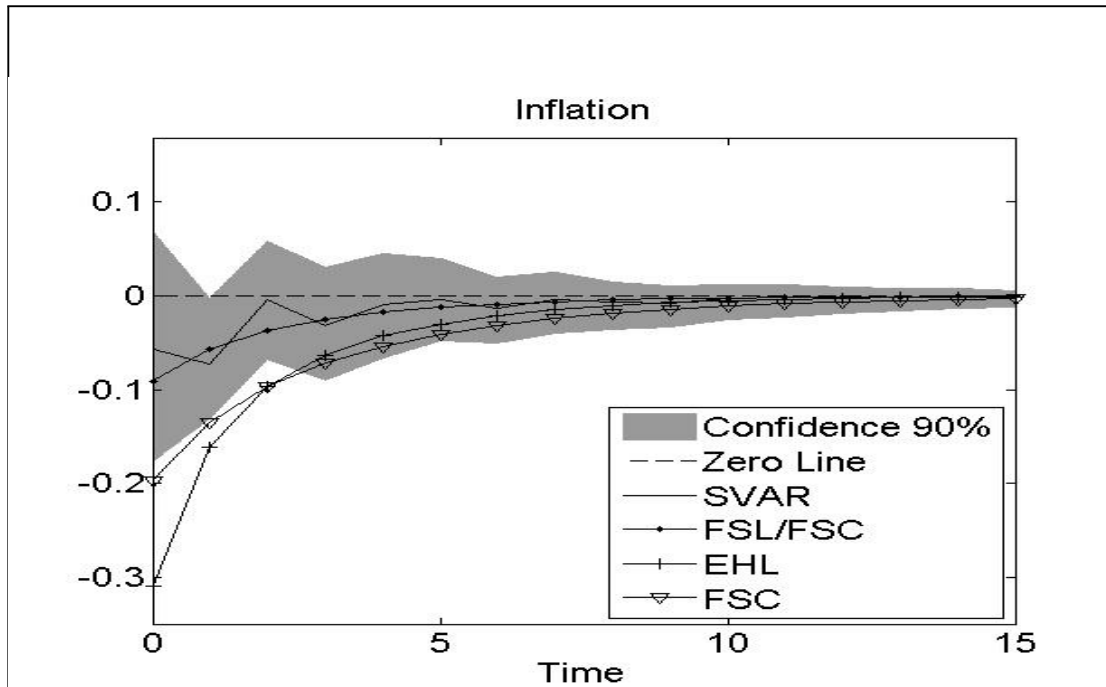


Figure 4: Impulse responses to a one-percent permanent innovation to technology in the models under the simple rule and in the data. Confidence bands are based on 999 bootstrap replications. SVAR corresponds to the median response in the bootstrap distribution.

identify technology shocks we rely on the same identification scheme as in Liu and Phaneuf (2007), building on work by Galí (1999), by assuming that the technology shock is the only shock that has a long-run impact on the level of average labor productivity. We limit the sample to the Volcker-Greenspan period 1982:3-2006:1 in order to focus on a period where one can plausibly argue that systematic policy has remained stable.

In figure 4 we plot the empirical inflation impulse-response to a one-percent permanent shock to technology. As can be seen in the figure, the point estimate indicates a moderate initial response of inflation of about 0.06 percent, which then tends back towards zero. Figure 4 also reports 90-percent bootstrap confidence bands showing that only the negative effect on inflation after one quarter is significantly different from zero. We have also plotted the impulse responses of the models outlined above to a one-percent technology shock.²⁵ In order to mimic the behavior to a permanent shock we set η to 0.9999 when computing theoretical impulse responses in this section.²⁶ As seen in the figure 4, the inflation response from the model with firm-specific labor is very well aligned with the empirical point estimate of the inflation response from the SVAR, staying well inside the empirical

²⁵Note that the natural real wage moves one-to-0.97 with the technology shock in the models above.

²⁶Thus relying on the continuity of the solutions.

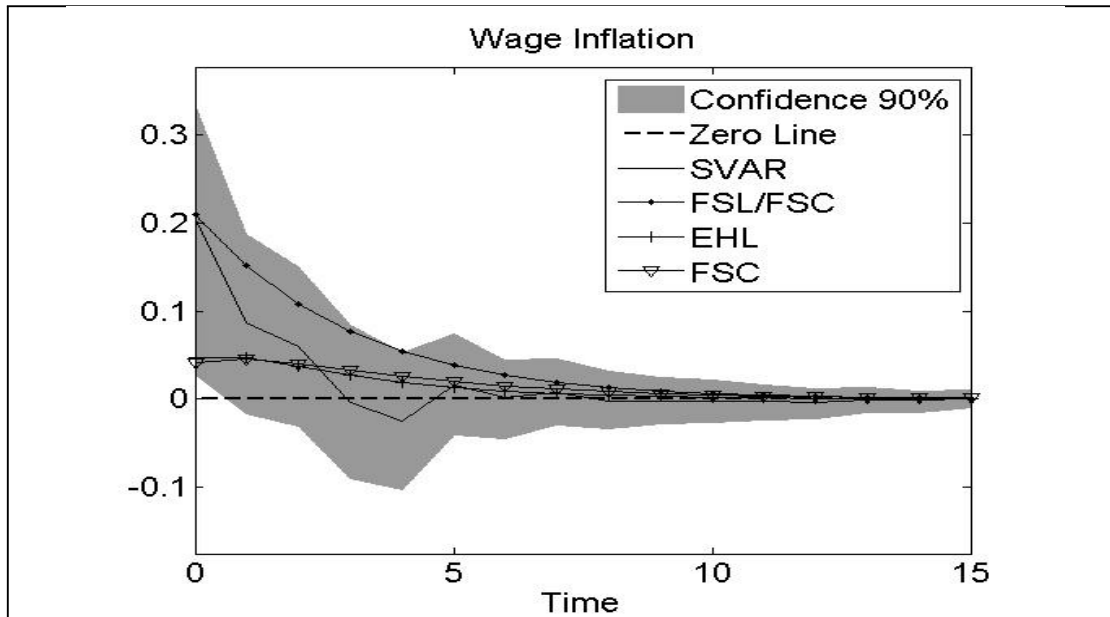


Figure 5: Impulse responses to a one-percent permanent innovation to technology in the models under the simple rule and in the data. Confidence bands are based on 999 bootstrap replications. SVAR corresponds to the median response in the bootstrap distribution.

confidence bands. On the other hand, the inflation response is too large in both the EHL and FSC models, with impulse responses outside of the confidence bands of the empirical impulse response for the first three quarters. In figure 5 we plot the empirical wage-inflation response together with 90-percent bootstrap confidence bands. As can be seen in the figure, there is a significantly positive initial response of wage inflation to a positive technology shock. The initial wage inflation response of the model with firm-specific labor is well aligned with the empirical impulse response, both implying an initial response of just above 0.2 percent. However, the model with firm-specific labor predicts a bit more persistence than the point estimate from the SVAR implies, but the model's wage-inflation response stays within the empirical confidence bands (except for just barely crossing outside at $t = 4$). The EHL and FSC models imply a much smaller initial wage-inflation response as compared to the point estimate of the SVAR. However, the wage-inflation response of these models stays within the empirical confidence bands.

7.3 Impulse Responses Under Optimal Policy

In figure 6, we plot the optimal commitment paths to an innovation in \hat{w}_t^* in the FSL/FSC model. Moreover, to get some intuition for the dynamics, we compare the responses under commitment with the responses under the simple rule and discretion, respectively.

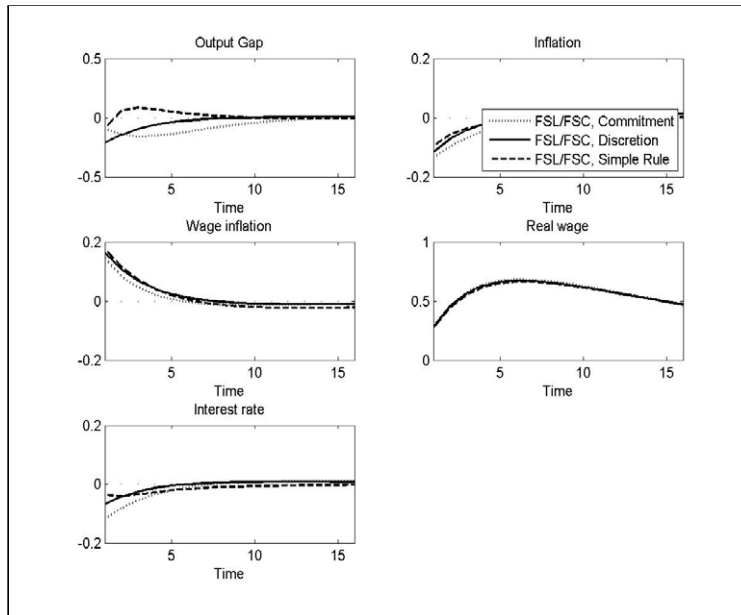


Figure 6: Impulse responses to a one-percent innovation to \hat{w}_t^* under optimal policy (commitment/discretion) and the simple rule.

When comparing optimal policy under commitment to policy under the simple rule, it is evident that the simple rule in terms of the response of interest rates initially reacts too little to the shock, as compared to optimal policy.²⁷ This leads to very different effects on the output gap through the Euler equation via the real interest rate and has consequences for the responses of the other variables - inflation decreases less and wage inflation increases more since the output gap is too high. Most importantly, the optimal policy is more successful in stabilizing wage inflation and hence wage dispersion, which is the most costly component in terms of welfare. An alternative way of viewing this is that it is more efficient in terms of welfare to adjust real wages by decreasing inflation than increasing wage inflation, pointing to the importance of flexible inflation targeting. When comparing optimal policy under discretion and commitment, the inflation and wage inflation response is fairly similar. The differences lies in the medium-term response for the output gap. This is due to that, in the commitment solution, the central bank uses its influence over expectations in order to stabilize wage-inflation variation, which, together with inflation, is a key cost component in the loss function (24), through more aggressive movements in the output gap. This, in turn, is also reflected in a more aggressive response of the interest rate under commitment.

²⁷The form and the parameters of the simple rule are chosen to fit the data and the simple rule is thus not necessarily optimal. Furthermore, note that adding wage inflation to the Taylor rule and solving optimally for the parameters need not implement the commitment policy, since a rule that would implement the commitment policy depends on the price level instead of inflation; see Galí (2008), page 106 (note also that there is not a unique rule that implements the commitment policy).

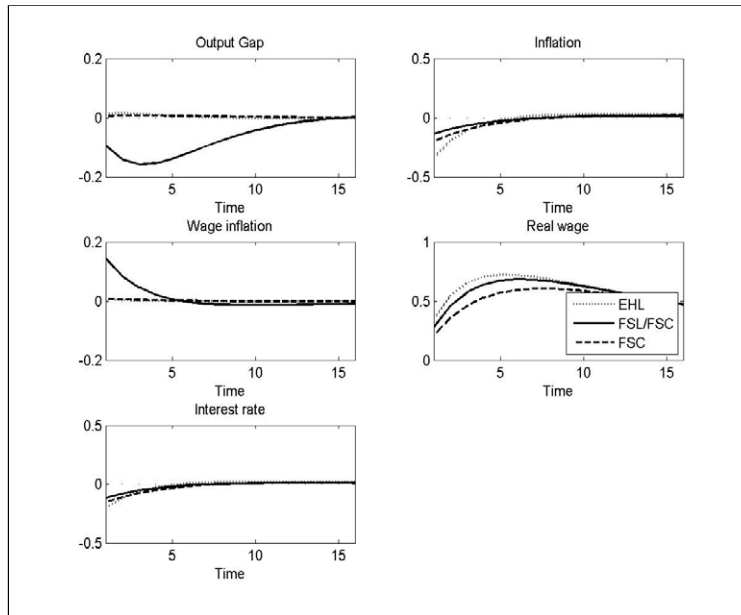


Figure 7: Impulse responses to a one-percent innovation to \hat{w}_t^* under optimal policy.

In figure 7 we compare optimal commitment paths across models. As can be seen in the figure, there are fairly big differences between the models. The output-gap response is substantially different in the FSL/FSC model, as compared to the other two models. Specifically, in the models with mobile labor, the output gap hardly responds at all to the shock. With firm-specific labor, the response is hump-shaped and the output gap decreases significantly. The inflation response is again substantially smaller in the FSL/FSC model, as compared to the other two models. An important difference between models is that the wage-inflation response is much larger in the model with firm-specific labor. Since the coefficient on variation in wage inflation in the loss function increases by a factor of around 1.5 when introducing firm-specific labor, the inability to replicate the almost complete stabilization of wage inflation in the models with freely mobile labor stems from changes in the constraints (18) and (19) on optimal policy from private sector behavior. Again, as discussed above in section 3.1, wage inflation hardly responds at all in the EHL and FSC models to innovations in the real-wage gap, which has a major effect on the optimal choices of the central bank. Furthermore, optimal policy also implies a more aggressive response of the interest rate in the EHL model as compared to the other two models.

7.4 Robustness

The results presented above are rather insensitive to variations in a number of parameters (see appendix C for details). For example, varying the intertemporal elasticity of substitution $1/\rho_C$, the Frisch

elasticity of labor supply, $1/\rho_L$, the replacement rate, b/w , and the bargaining power has only small effects on impulse responses under both the simple rule and optimal policy.²⁸ Thus, we do not see a strong impact on the equilibrium dynamics from varying the parameters related to labor-market institutions. Finally, under the commitment policy we see a substantial flattening of the inflation response in the model with firm-specific labor when α tends towards unity and price and wage decisions become perfectly synchronized. The inflation response in the model with freely mobile labor also flattens as α tends to unity (implying equal durations of wage and price contracts) under both types of policy, but not by nearly as much. Furthermore, using a family construct to achieve consumption insurance in the EHL model instead of the original setup of Erceg et al. (2000) yields almost identical impulse responses.

8 Concluding Remarks

In this paper, we develop a model with firm-specific labor with both staggered prices and wages where wages are set unilaterally by unions within individual firms. Based on empirical evidence, we introduce a modification of price- and wage-setting behavior in the Calvo framework. Specifically, we allow prices to be changed whenever wages are. This assumption greatly simplifies the analysis of the problem. In particular, complicated interdependencies between current and future price and wage decisions that would be present in the standard Calvo framework are eliminated. This gives rise to a simple and more realistic representation of the labor market that can be used as a building block in a much richer model than presented here.

In line with a growing literature studying the role of strategic complementarity arising through firm-specific factors, we find that firm-specific labor, through the price- and wage-setting relationships, substantially flattens the New Keynesian Phillips Curve. This leads to a much smaller inflation response as compared to models with freely mobile labor. Furthermore, firm-specific labor leads to a larger response of wage inflation. When comparing across models with and without freely mobile labor, we find that the model with firm-specific labor does a significantly better job in matching the empirical inflation and wage-inflation responses derived from a SVAR.

Further, we find that allowing for non-synchronized wage and price setting has important effects on the inflation response. In particular, when price and wage changes are completely synchronized, as in Kuester (2010), price-setting behavior is very much altered and inflation hardly responds at all to productivity shocks.

The model-consistent welfare measure derived in this paper indicates that the main effect of intro-

²⁸To allow for firm bargaining power the model has to be slightly modified, for details see Appendix A.

ducing firm-specific labor is that the loss associated with inflation variability increases dramatically. This is because price dispersion leads to variation in labor supply across households when they are attached to a firm. Optimal policy is characterized by similar responses for inflation and wage inflation as compared to a simple a Taylor (1993)-type rule with interest-rate smoothing across all three models. On the other hand, optimal policy implies a different response for the output gap and a much more aggressive response of the interest rate in all models as compared to the simple rule.

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Appendix

A Firm bargaining power

When the firm has bargaining power, we solve for the wage by maximizing the Nash product²⁹

$$\max_{W(f)} (U_{t,t}^t - U_{o,t})^\varphi (F_{t,t}^t - F_{o,t})^{1-\varphi}, \quad (30)$$

where φ is the relative bargaining power of households, $U_{o,t}$ is the threat point for the households and $F_{t,t}^t$ ($F_{o,t}$) denotes the value (threat point) for the firm. The threat point is the payoff when there is disagreement during the period (i.e. strike or lockout). During a period when there is a strike, i.e. the firm does not accept the offer by the worker, households are assumed to receive b and not spend any time working. Moreover, since the threat point is defined as a one period delay in the bargaining, the expected discounted payoff from subsequent periods also enters each party's threat point.³⁰ Given the wage, the firm decides upon employment each period. This seems to be in line with empirical evidence.³¹

The main difference in the wage determination between this representation of the labor market relative to the search-matching framework in Gertler and Trigari (2009), Gertler, Sala, and Trigari (2008), Krause and Lubik (2007), Kuester (2010) and others, is that the outside option of a household does not depend upon aggregate conditions directly.³² That is, the attachment of a worker to a firm remains even when not working. Indirectly, however, aggregate conditions will affect the surplus, $U_{t,t}^t - U_{o,t}$, e.g. via the probability of employment now and in the future. Although the lack of a direct effect is a potential weakness of the model, the importance of this direct effect on wage determination has recently been questioned by Hall and Milgrom (2008).³³ It is interesting to note, though, that the wage-setting relationship we derive is very similar to that of a search model.

²⁹We think of bargaining as non-cooperative (see Rubinstein, 1982), but rely on the equivalence result in Rubinstein (1982) between non-cooperative bargaining and the Nash bargaining solution.

³⁰This interpretation of threat points is in line with a standard Rubinstein-Ståhl bargaining model as presented in Binmore, Rubinstein, and Wolinsky (1986) (see also Mortensen, 2005, for an application of this bargaining setup).

³¹As pointed out by Layard, Nickell, and Jackman (2005), chapter 2, employment is rarely bargained over empirically. Note also that, in noncooperative bargaining models of the Rubinstein-Ståhl-type, efficient bargaining (generically) becomes inefficient when there is more than a single employee bargaining with the firm, see Björnerstedt and Westermark (2009).

³²The method proposed in this paper can of course also be applied in a search-matching framework.

³³The argument of Hall and Milgrom (2008) is that the threat points should not be sensitive to factors like unemployment or the average wage in the economy since delay is the relevant threat as opposed to permanently terminating the relationship between the firm and the workers. For example, United Auto Workers permanently walking away from Ford is never on the table during wage negotiations.

The payoff in case there is a conflict is, for the union,

$$U_{o,t} = \Upsilon_{o,t} + \beta E_t \frac{u_{C,t+1}}{u_{C,t}} U_{t+1,t+1}^{t+1}, \quad (31)$$

where

$$\Upsilon_{o,t} = b - \frac{v(0, Z_{t+k+j})}{u_{C,t+k+j}}. \quad (32)$$

Some algebra establishes that

$$\begin{aligned} U_{t,t}^t - U_{o,t} &= \Upsilon_{t,t}^t - \Upsilon_{o,t} + \sum_{k=1}^{\infty} (\alpha_w \alpha \beta)^k E_t \frac{u_{C,t+k}}{u_{C,t}} (\Upsilon_{t,t+k}^t - \Upsilon_{t+1,t+k}^t) \\ &\quad + \alpha_w \beta \sum_{k=0}^{\infty} (\alpha_w \alpha \beta)^k E_t \frac{u_{C,t+k+1}}{u_{C,t}} (\Upsilon_{t+1,t+k+1}^t - \Upsilon_{t+1,t+k+1}^{t+1}) \\ &\quad + (1 - \alpha) \sum_{k=2}^{\infty} (\alpha_w \beta)^k \sum_{j=0}^{\infty} (\alpha_w \alpha \beta)^j E_t \frac{u_{C,t+j+k}}{u_{C,t}} (\Upsilon_{t+k,t+j+k}^t - \Upsilon_{t+k,t+j+k}^{t+1}). \end{aligned} \quad (33)$$

The values have the same structure as for households (see (14)), and we have

$$\begin{aligned} F_{t,t}^t &= \phi_{t,t}^t + \alpha_w \beta E_t \frac{u_{C,t+1}}{u_{C,t}} (\alpha F_{t,t+1}^t + (1 - \alpha) F_{t+1,t+1}^t) \\ &\quad + (1 - \alpha_w) \beta E_t \frac{u_{C,t+1}}{u_{C,t}} F_{t+1,t+1}^{t+1}, \end{aligned} \quad (34)$$

$$F_{o,t} = 0 + \beta E_t \frac{u_{C,t+1}}{u_{C,t}} F_{t+1,t+1}^{t+1}, \quad (35)$$

where per-period real profit in period $t+k+j$, when prices last were changed in $t+k$ and wages in t , is denoted as

$$\phi_{t,t+k+j}^t = (1 + \tau) \frac{P_{t+k}^o(f)}{P_{t+k+j}} Y_{t+k+j}(f) - tc \left(\frac{W_t(f)}{P_{t+k+j}}, Y_{t+k+j}(f) \right). \quad (36)$$

The per-period payoff of the firm when there is a strike is assumed to be zero. An expression similar to (33) can be derived for $F_{t,t}^t - F_{o,t}$ (see the technical appendix for details). The wage setting curve (19) now becomes

$$\begin{aligned} \hat{\pi}_t^\omega &= \beta E_t \hat{\pi}_{t+1}^\omega - \Omega_x \hat{x}_t - \Omega_w (\hat{w}_t - \hat{w}_t^*) \\ &\quad - \Omega_n^{+1} (E_t \hat{\pi}_{t+1}^\omega - \beta E_t \hat{\pi}_{t+2}^\omega) - \Omega_x^{+1} E_t \hat{x}_{t+1} - \Omega_w^{+1} E_t (\hat{w}_{t+1} - \hat{w}_{t+1}^*), \end{aligned} \quad (37)$$

where Ω_n^{+1} , Ω_x^{+1} and Ω_w^{+1} are defined in appendix B.

Note that, in case the firm has some bargaining power, the structure of the wage-setting curve is similar to models with a search-matching framework on the labor market, see (37). It is easy to show,

by using (17) and (18) in (37), that we get a wage-setting curve with both lagged and future wages as in e.g. Gertler, Sala, and Trigari (2008). The reason is that both models rely on a bargaining model to determine wages and that the bargaining outcome is influenced by the parties' outside options.

B Derived Parameters

In the technical appendix, letting

$$\varepsilon_L = \frac{\partial L_t(f) W(f)}{\partial W(f) L_t(f)} = -\sigma \frac{1}{1-\gamma}, \quad (38)$$

$$\Pi_1 = (1 - \alpha_w \beta) \frac{1 - \alpha_w}{\alpha_w}, \quad (39)$$

we derive the coefficients in the wage setting curve (19) as

$$\begin{aligned} \Omega_x &= \Pi_1 \frac{\Phi_x}{\Phi_n}, \\ \Omega_w &= \Pi_1, \\ \Omega_n^{+1} &= \frac{\Phi_n^{+1}}{\Phi_n}, \\ \Omega_x^{+1} &= \Pi_1 \frac{\Phi_x^{+1}}{\Phi_n}, \\ \Omega_w^{+1} &= \Pi_1 \Omega_n^{+1}, \end{aligned} \quad (40)$$

where

$$\begin{aligned} \Phi_n &= \varphi \frac{\bar{w}\bar{L}}{W_t(f)} \varepsilon_L \left(1 + \frac{b}{\bar{w}} - \frac{\sigma}{1-\gamma} \frac{1}{1 + \sigma \frac{\gamma}{1-\gamma} \rho_L} \right) + (1 - \varphi) \frac{1}{1 - \alpha_w \beta} \frac{\bar{w}\bar{L}}{W_t(f)} \\ &\quad \times \left(\frac{b}{\bar{w}} - \varepsilon_L \frac{1}{1 + \sigma \frac{\gamma}{1-\gamma}} + \left(\frac{V(\bar{L}, \bar{Z})}{\bar{u}_C \bar{w}\bar{L}} - \frac{V(0, \bar{Z})}{\bar{u}_C \bar{w}\bar{L}} \right) \frac{1 - \sigma}{1 + \sigma \frac{\gamma}{1-\gamma}} \right) \frac{(1 - \sigma)}{1 + \frac{\gamma}{1-\gamma} \sigma}, \\ \Phi_n^{+1} &= - (1 - \varphi) \frac{\alpha_w \beta}{1 - \alpha_w \beta} \frac{\bar{w}\bar{L}}{W_t(f)} \\ &\quad \times \left(\frac{b}{\bar{w}} - \varepsilon_L \frac{1}{1 + \sigma \frac{\gamma}{1-\gamma}} + \left(\frac{V(\bar{L}, \bar{Z})}{\bar{u}_C \bar{w}\bar{L}} - \frac{V(0, \bar{Z})}{\bar{u}_C \bar{w}\bar{L}} \right) \frac{1 - \sigma}{1 + \sigma \frac{\gamma}{1-\gamma}} \right) \frac{(1 - \sigma)}{\left(1 + \frac{\gamma}{1-\gamma} \sigma \right)}, \end{aligned} \quad (41)$$

and

$$\begin{aligned}
\Phi_x &= \varphi \frac{\bar{w}\bar{L}}{W_t(f)} \varepsilon_L \left(\rho_L \frac{1}{1-\gamma} \frac{1}{1+\sigma \frac{\gamma}{1-\gamma}} - \rho_C \right) + (1-\varphi) \frac{1}{1-\alpha_w\beta} \frac{(1-\sigma)}{1+\frac{\gamma}{1-\gamma}\sigma} \frac{\bar{w}\bar{L}}{W_t(f)} \\
&\quad \times \left(\left(\frac{V(\bar{L}, \bar{Z})}{\bar{u}_C \bar{w}\bar{L}} - \frac{\bar{V}(0, \bar{Z})}{\bar{u}_C \bar{w}\bar{L}} \right) \left(\frac{1}{1-\gamma} \frac{1}{1+\sigma \frac{\gamma}{1-\gamma}} - \rho_C \right) - \frac{1}{1-\gamma} \frac{1}{1+\sigma \frac{\gamma}{1-\gamma}} \right), \quad (42) \\
\Phi_x^{+1} &= -(1-\varphi) \frac{\alpha_w\beta}{1-\alpha_w\beta} \frac{(1-\sigma)}{1+\frac{\gamma}{1-\gamma}\sigma} \frac{\bar{w}\bar{L}}{W_t(f)} \\
&\quad \times \left(\left(\frac{V(\bar{L}, \bar{Z})}{\bar{u}_C \bar{w}\bar{L}} - \frac{\bar{V}(0, \bar{Z})}{\bar{u}_C \bar{w}\bar{L}} \right) \left(\frac{1}{1-\gamma} \frac{1}{1+\sigma \frac{\gamma}{1-\gamma}} - \rho_C \right) - \frac{1}{1-\gamma} \frac{1}{1+\sigma \frac{\gamma}{1-\gamma}} \right).
\end{aligned}$$

In the technical appendix we derive the following parameters for the welfare gap expression (24):

$$\begin{aligned}
\theta_x &= \frac{\Lambda^* \bar{C}}{2} = \frac{\bar{u}_C \bar{C}}{2} \left(-\rho_C + \rho_L \frac{1}{1-\gamma} - \frac{\gamma}{1-\gamma} \right), \\
\theta_\pi &= - \left(\bar{u}_C \bar{C} \frac{1}{2} \sigma^2 \left(\frac{1-\sigma}{\sigma} + \frac{1-\rho_L}{1-\gamma} \right) \right) \frac{1}{\Pi_W}, \quad (43) \\
\theta_{\pi^w} &= - \left(\bar{u}_C \bar{C} \frac{1}{2} \sigma^2 \left(\frac{1-\sigma}{\sigma} + \frac{1-\rho_L}{1-\gamma} \right) \right) \left(-\frac{1}{\Pi_W} + \frac{1}{\Pi_1} \right),
\end{aligned}$$

where

$$\Pi_W = (1 - \alpha_w \alpha \beta) \frac{1 - \alpha_w \alpha}{\alpha_w \alpha}.$$

For the EHL model, the wage setting curve is

$$\hat{\pi}_t^w = \beta E_t \hat{\pi}_{t+1}^w - \Omega_w^{EHL} (\hat{w}_t - \hat{w}_t^*) + \Omega_x^{EHL} \hat{x}_t.$$

The wage-setting curve in the FSC model is identical in shape. The coefficients are

$$\begin{aligned}
\Omega_w^{EHL} &= \Omega_w^{FSC} = \frac{\Pi_1}{1 - \rho_L \sigma_w}, \quad (44) \\
\Omega_x^{EHL} &= \Omega_x^{FSC} = \Omega_w^{EHL} \left(\rho_C - \rho_L \frac{1}{1-\gamma} \right),
\end{aligned}$$

where σ_w is the elasticity of labor demand. The New Keynesian Phillips Curve is, in the EHL model,

$$\hat{\pi}_t = \beta E_t \hat{\pi}_{t+1} + \Pi_W (\hat{w}_t - \hat{w}_t^*) + \frac{\gamma}{1-\gamma} \Pi_W \hat{x}_t \quad (45)$$

and, in the FSC model,

$$\hat{\pi}_t = \beta E_t \hat{\pi}_{t+1} + \Pi (\hat{w}_t - \hat{w}_t^*) + \frac{\gamma}{1-\gamma} \Pi \hat{x}_t. \quad (46)$$

Finally, the loss function parameters are

$$\begin{aligned}
 \theta_x^{EHL} &= \theta_x^{FSC} = \theta_x, \\
 \theta_\pi^{EHL} &= -\frac{1}{2}\bar{u}_C\bar{C}\sigma\frac{1}{\Pi_W}, \\
 \theta_\pi^{FSC} &= -\frac{1}{2}\bar{u}_C\bar{C}\left(\frac{1-\gamma+\sigma\gamma}{1-\gamma}\right)\sigma\frac{1}{\Pi_W}, \\
 \theta_{\pi^\omega}^{EHL} &= \theta_{\pi^\omega}^{FSC} = -\frac{1}{2}\bar{u}_C\bar{C}(1-\gamma)\sigma_w(1-\rho_L\sigma_w)\frac{1}{\Pi_1}.
 \end{aligned}$$

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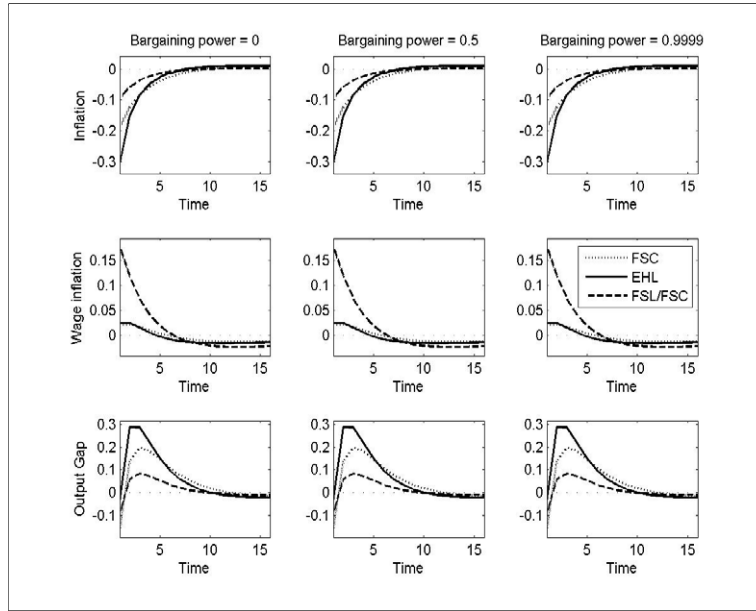


Figure 8: Impulse responses to a one-percent innovation to \hat{w}_t^* when the nominal interest rate is governed by the simple rule for different values of the bargaining power.

C Robustness

In this appendix we study the robustness of the results presented above in detail. In figures 8 to 12 we study the sensitivity of the impulse responses for $\hat{\pi}_t$, $\hat{\pi}_t^\omega$ and \hat{x}_t to variations in φ , ρ_C , ρ_L , b/w and α in the three models under the simple rule (25).³⁴

Overall, the results are rather insensitive to perturbations of the parameters around the baseline calibration. We still see a substantial difference in the initial inflation response to a real-wage shock. Also, as can be seen from figure 12, varying the price adjustment probability has substantial effects in the model with firm-specific labor as α tends towards unity. In particular, note the differences between the case when $\alpha = 1$ and $\alpha < 1$. This, of course, replicates the result presented in figure 3. However, figure 12 also show that the impulse response for inflation in the model with freely mobile labor does not flatten nearly as much when increasing α towards an equal duration of prices and wages, as implied by setting α equal to unity (remember that we hold average duration of price and wage contracts equal across models when comparing them). This is because setting wage and price duration equal in the EHL and FSC framework does not imply a perfect synchronization of price and wage setting as in the model with firm-specific labor (see the discussion in section 7.1 on the effects of synchronization of price and wage decisions).

³⁴The variation we do for ρ_L is constrained by the ability of finding a steady state of the models.

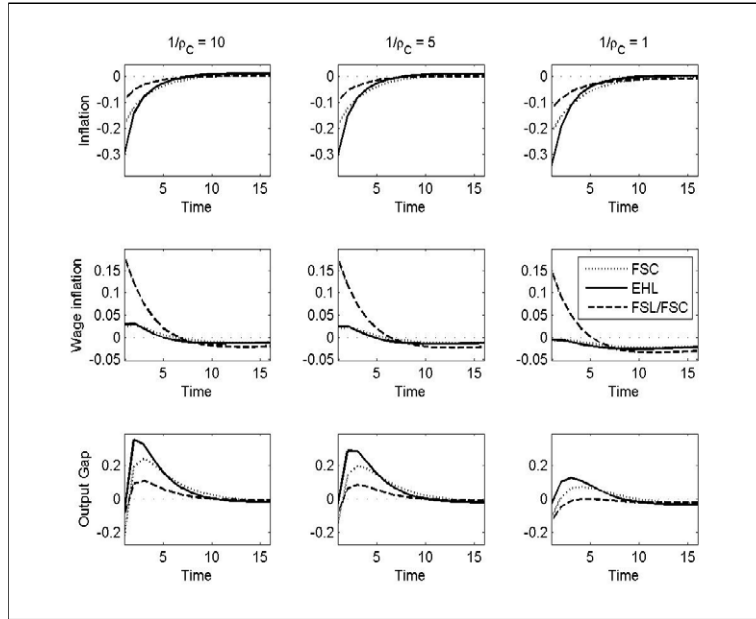


Figure 9: Impulse responses to a one-percent innovation to \hat{w}_t^* when the nominal interest rate is governed by the simple rule for different values of the intertemporal elasticity of substitution in consumption.

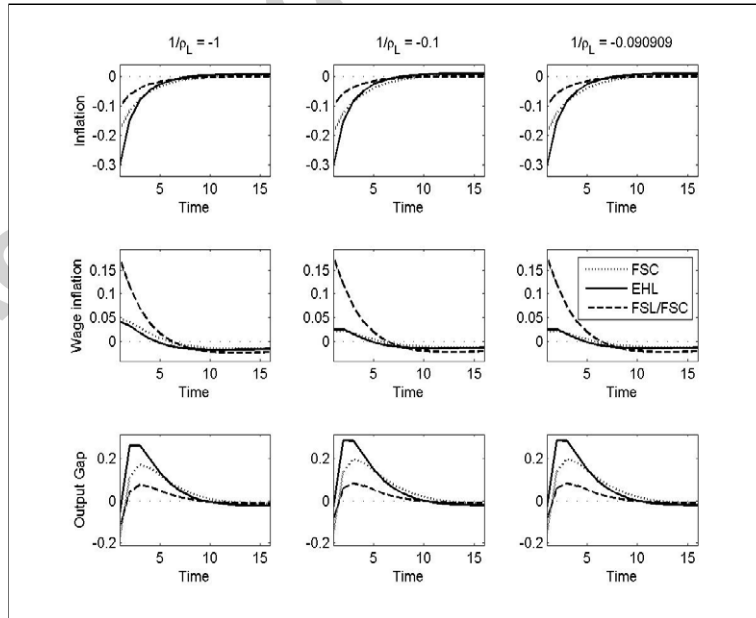


Figure 10: Impulse responses to a one-percent innovation to \hat{w}_t^* when the nominal interest rate is governed by the simple rule for different values of the Frisch labor-supply elasticity.

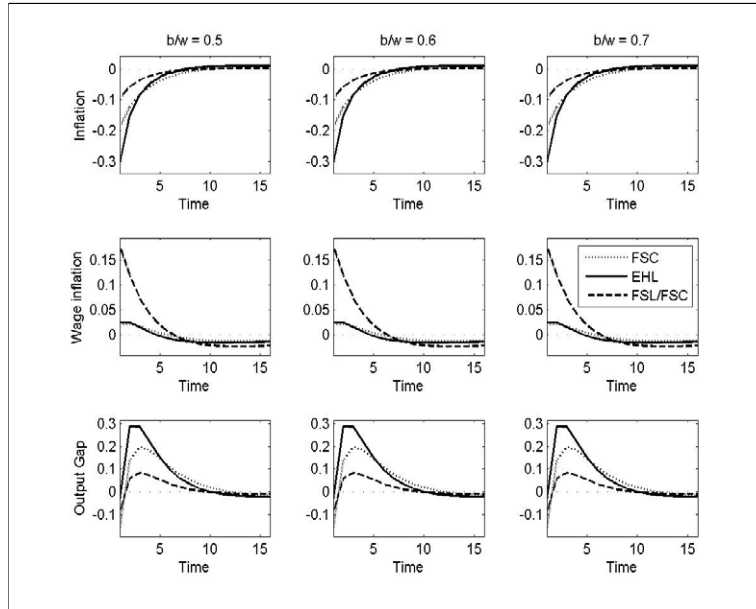


Figure 11: Impulse responses to a one-percent innovation to \hat{w}_t^* when the nominal interest rate is governed by the simple rule for different values of the replacement rate.

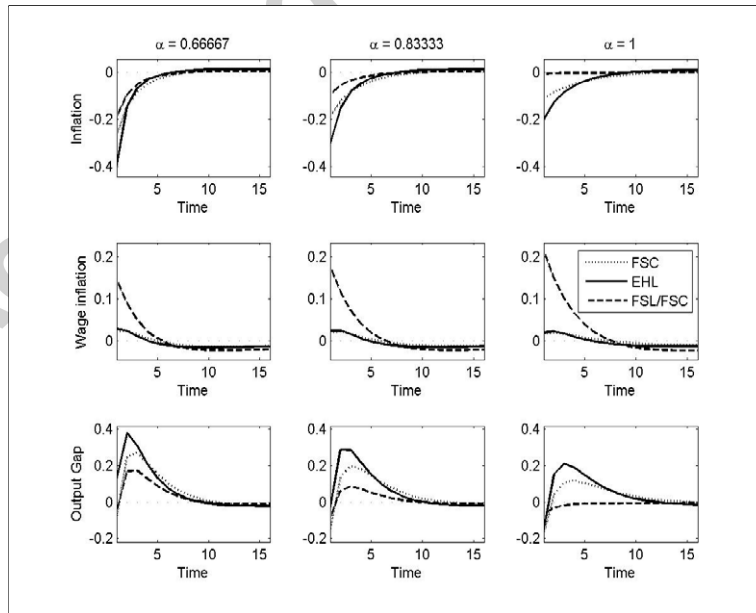


Figure 12: Impulse responses to a one-percent innovation to \hat{w}_t^* when the nominal interest rate is governed by the simple rule for different values of the price adjustment probability α .

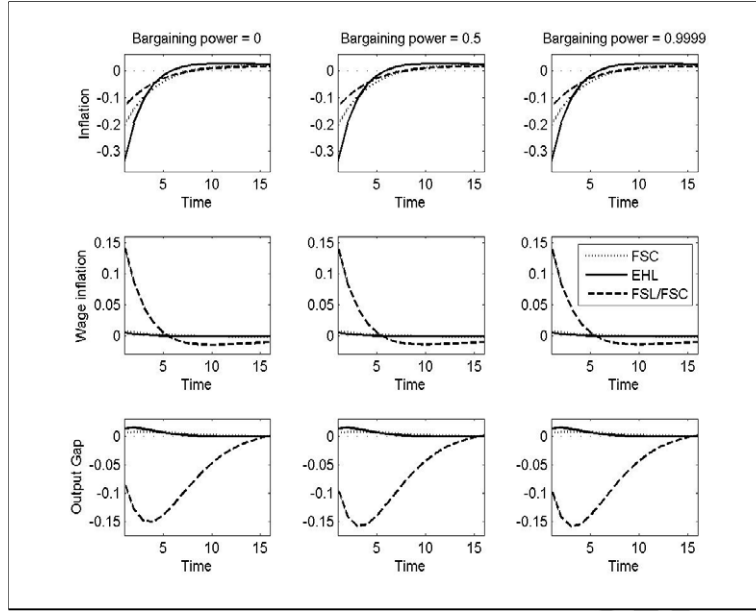


Figure 13: Impulse responses to a one-percent innovation to \hat{w}_t^* under optimal policy for different values of the bargaining power.

Next, in figures 13 to 17, we look at the sensitivity of the impulse responses for $\hat{\pi}_t$, $\hat{\pi}_t^\omega$ and \hat{x}_t to variations in φ , ρ_C , ρ_L , b/w and α in the three models under the optimal commitment policy. The robustness of the results is confirmed by figures 13 to 17. The results from varying the price adjustment probabilities, displayed in figure 17, indicate that there is still a substantial difference between when $\alpha = 1$ and $\alpha < 1$. Again, perfectly synchronizing wage and price changes in the model with firm-specific labor substantially flattens the inflation response even under optimal policy. Note also that if $\alpha = 1$ then optimal policy completely stabilizes the output gap and inflation in the FSL/FSC model. The reason is that, as can be seen from setting $\Pi_W = \Pi_1$ in (43), we have $\theta_{\pi^\omega} = 0$, implying that the cost of wage variability is zero. The central bank can then fully stabilize the output gap and inflation and let wage inflation be determined residually.

Finally, we have also studied whether relying on a family construct in the EHL model, in contrast to the original Erceg et al. (2000) formulation, affects the impulse-response functions. As shown in figure 18, this hardly affects the impulse-responses at all.

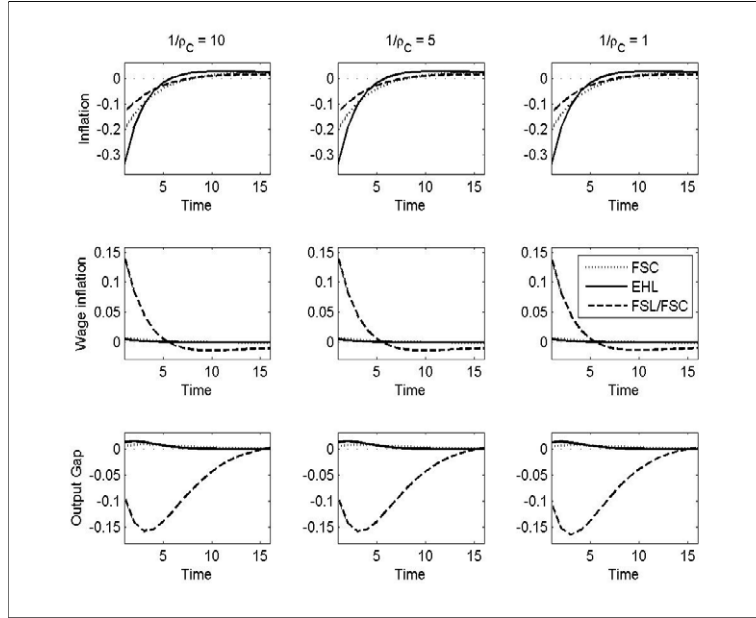


Figure 14: Impulse responses to a one-percent innovation to \hat{w}_t^* under optimal policy for different values of the intertemporal elasticity of substitution in consumption.

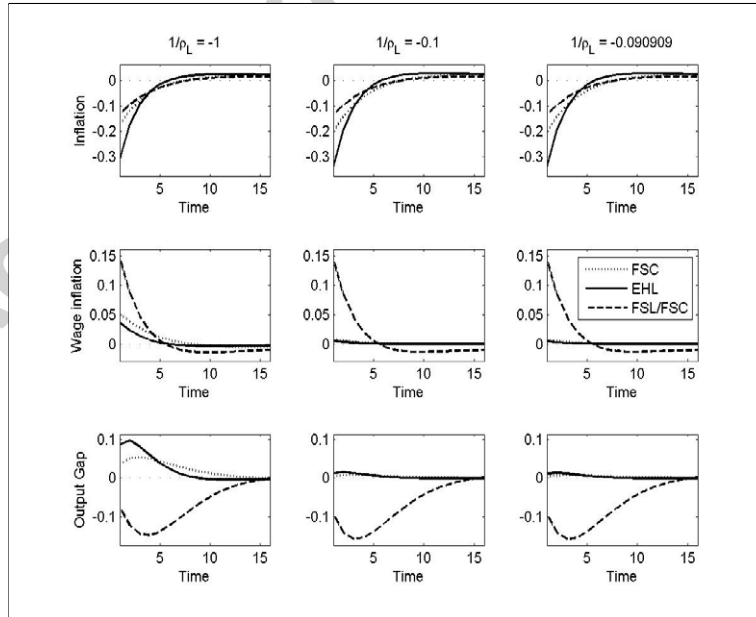


Figure 15: Impulse responses to a one-percent innovation to \hat{w}_t^* under optimal policy for different values of the Frisch labor-supply elasticity.

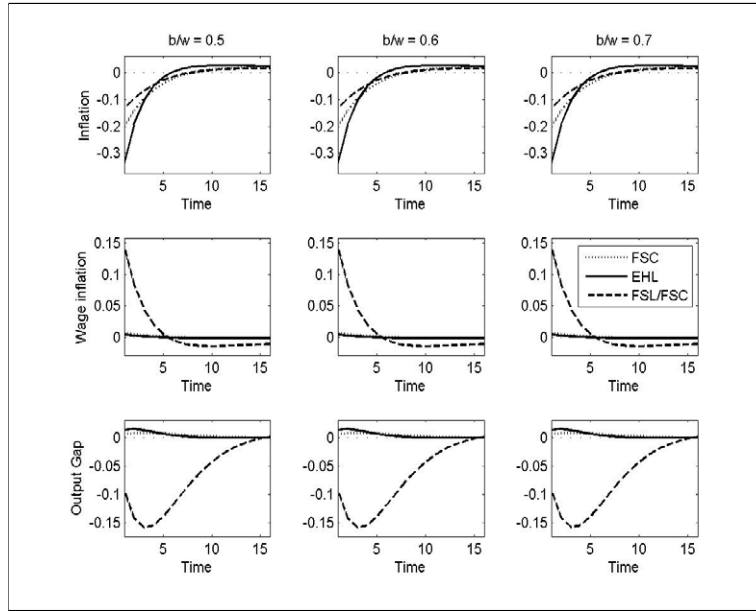


Figure 16: Impulse responses to a one-percent innovation to \hat{w}_t^* under optimal policy for different values of the replacement rate.

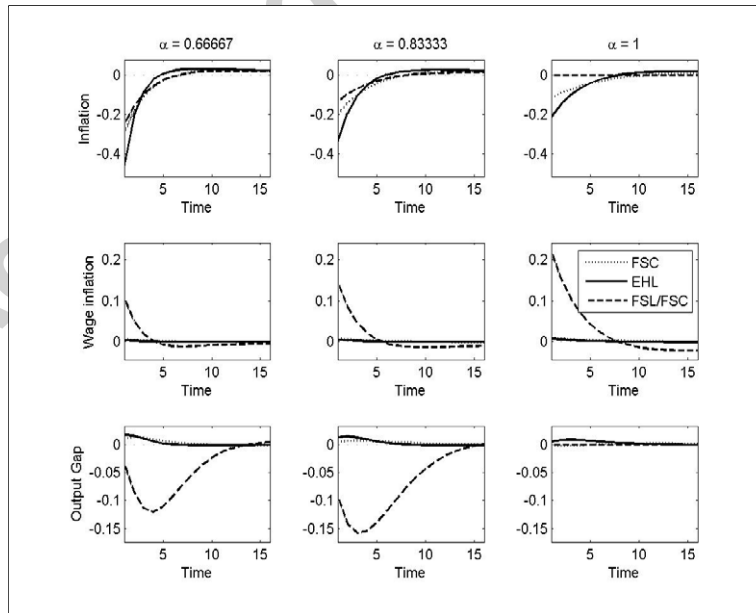


Figure 17: Impulse responses to a one-percent innovation to \hat{w}_t^* under optimal policy for different values of the price adjustment probability α .

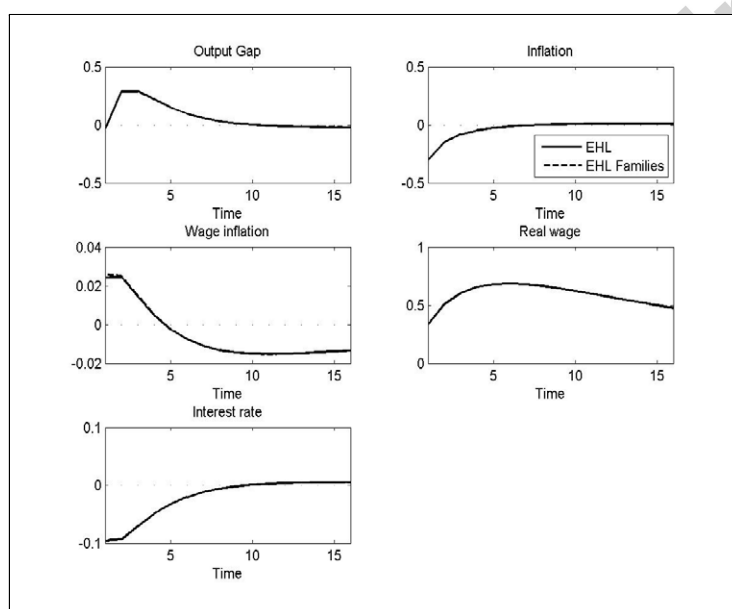


Figure 18: Impulse responses to a one-percent innovation to \hat{w}_t^* when the nominal interest rate is governed by the simple rule in the EHL model with and without relying on a family construct.