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 firm-level wage bargaining 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 is supported by empirical evidence from a structural VAR.

Keywords: Monetary Policy, Inflation Persistence, Labor Market, Bargaining.

JEL classification: E52, E58, J41.

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1 Introduction

In a growing literature, a number of papers has studied the role of firm-specific factors in generating 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 (2004). 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 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.

Typically, wages are determined in a bargain between the firm and the workers. However, introducing both Calvo-type staggered prices and wages when wages are bargained over 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 bargaining via the firm's future surpluses. Since bargained wages will be different, marginal cost is also affected, leading to changes in future optimal prices. Thus, under firm-specific wage bargaining, 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 (2007).[2]

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

[1] See e.g. Smets and Wouters (2003), Altig, Christiano, Eichenbaum, and Linde (2004), Christiano, Eichenbaum, and Evans (2005), Adolfson, Laséen, Lindé, and Villani (2008) and others.

[2] Note that the price- and wage-setting model of Kuester (2007) 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 bargaining is opened with some fixed probability in each period. Price setting is slightly different from Calvo (1983). Specifically, any firm that is allowed to change wages, can also change prices. Firms that do not change wages are selected with some fixed probability to change prices, as in Calvo (1983). This modification is in line with the micro evidence (see Altissimo, Ehrman and Smets, 2006). The key aspect of this assumption is that it greatly simplifies our problem. Especially, it eliminates the interdependence between current and future prices. Similarly, the interdependence between current and future wage contracts is eliminated.

The wage-setting relationship in our model is substantially altered as compared to the EHL framework. First, since wages will be set in a bargain between the firm and the workers there will be additional forward-looking terms in the wage-setting curve in the current model stemming from effects via the outside option. This feature is similar to models based on a search-matching framework, which also incorporate bargaining over wages. Secondly, 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 bargaining surplus) and wage inflation. Finally, since wages are bargained over, and not set unilaterally by the workers, the relationship between wage inflation and the output-gap become ambiguous. That is, since firms desire to set wages equal to the marginal product of labor they want to lower wages in response to a positive output gap, whereas workers want to set the real wage equal to the value of the marginal rate of substitution between leisure and consumption and thus wants to increase wages. 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), as well as, 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 firm-specific capital but with freely mobile labor. This, in turn, leads to a much smaller inflation response in the FSL/FSC model as compared to the FSC (and the EHL) model.[3] This is due to a much larger wage inflation response in the model with firm-specific labor. Thinking of a productivity shock, the reason why inflation responds much less with firm-specific labor is that when both wages and prices are changed within a firm, a productivity increase decreases marginal cost, for a given wage, but at the same time leads to an increase in wages via the bargaining surplus causing an upward pressure on marginal cost

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

and, in turn, leading to a small net effect of productivity on prices. Hence, inflation response little to productivity.

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 match the point estimate of the empirical inflation response very well. Moreover, the model also match the initial empirical wage inflation response, though predicting a little too much persistence in the intermediate term. In contrast, both the EHL model and the FSC model imply too large 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. Especially, when price and wage changes are completely synchronized, as in Kuester (2007), price-setting behavior is very much altered as compared to our baseline calibration and inflation hardly responds at all to productivity shocks.

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 due to that price dispersion lead to variation in labor supply between households since they are attached to a given firm in the FSL/FSC framework.

Optimal policy is characterized by similar responses as compared to a simple a Taylor (1993) type rule with interest-rate smoothing for inflation and wage inflation across all three models. 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 has 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 (2004). Overall, firm-specific capital generate a flattening of the New Keynesian Phillips Curve, allowing for a better fit with empirical observations. The mechanism works through 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 study 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]

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. Sections 6 discuss the baseline calibration. Section 7 report 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, bargaining over wages at a specific firm takes place with a fixed probability. Accordingly, wages are staggered as in Calvo (1983) and determined in firm-specific bargaining between the workers and the firm. Given the wage, the firm decides upon employment each period. This seems to be in line with empirical evidence.[6] The household derive 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 Westermark, 2008, for a full derivation).

2.1 Price and Wage Setting with Firm-Specific Labor

With firm-specific labor, the wage is determined in bargaining between the firm and a union representing the workers attached to the firm. This assumption together with staggered price- and wage-setting 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 bargained wage. An important implication of this is that there may be a relationship between wage negotiations today and in the future. The reason is that the wage set today affects prices

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

[5] There 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.

[6] As pointed out by Layard, Nickell, and Jackman (2005) 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 (2008).

set in the future which, in turn, act as a state variable in future wage negotiations. 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.

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.

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 the duration of wage contracts could never be longer than for prices, which seems 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 (24) below).

When introducing search frictions into a New Keynesian model with both staggered price- and wage-setting in the same sector, Kuester (2007) runs into the same interdependency problem since these frictions render workers (temporarily) firm specific. Kuester (2007) 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,

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

where $\sigma > 1$ and $Y_t\left(f\right)$ 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

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

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

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

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

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

where A_t is the technology level common to all firms and $L_t\left(f\right)$ denote the firms' labor input in period t. Since firms decide upon employment, $L_t\left(f\right)$ is chosen optimally, taking the bargained wage $W_t\left(f\right)$ as given. Note that the model can be though 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

$$MC_t\left(f\right) = \frac{W_t\left(f\right)}{MPL_t\left(f\right)}, \tag{5}$$

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

2.2.1 Prices

The firm is allowed to change prices in a given period with probability $1-\alpha$ and renegotiate wages with probability $1-\alpha_w$. As mentioned above, any firm where wages change can also change prices. Thus,

[7] Allowing 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.

the probability that a firm's price is unchanged is $\alpha_w \alpha$. The producers choose prices to maximize

$$\max_{p_t(f)} E_t \sum_{k=0}^{\infty} (\alpha_w \alpha)^k \Psi_{t,t+k} \left[(1+\tau) P_t(f) Y_{t+k}(f) - TC\left(W_{t+k}(f), Y_{t+k}(f)\right)\right] \quad (6)$$

$$\text{s. t. } Y_{t+k}(f) = \left(\frac{P_t(f)}{P_{t+k}}\right)^{-\sigma} Y_{t+k},$$

where $TC\left(W_{t+k}(f), y_{t+k}(f)\right)$ 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 just 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, has a continuum of members where a fraction is employed by the firm in the local labor market. Since the family pool 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 by[8]

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

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

[8] In 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.

balances, where M_s denotes money holdings, and $v(H^e)$ and $v(0)$ the disutility of being employed and unemployed, respectively. 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

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

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 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

As mentioned above, wages are determined in bargaining between the firm and a union representing the household attached to firm f. We think of bargaining as non-cooperative (see Rubinstein, 1982). We start by denoting the value for the family of the household attached to firm f in period $t+k+j$ is, given that prices were last changed in $t+k$ and wages in t by $U^t_{t+k,t+k+j}$. Similarly, we denote the value for the firm by $F^t_{t+k,t+k+j}$. Guided by the empirical evidence presented by Layard, Nickell, and Jackman (2005), chapter 2, we assume that there is no bargaining over employment, implying bargaining over wages only, but recognizing that the bargained wage will affect the firm's labor choice. Relying on the equivalence result in Rubinstein (1982) between non-cooperative bargaining and the Nash bargaining solution, we solve for the wage from maximizing the Nash product

$$\max_{W(f)} \left(U^t_{t,t} - U_{o,t}\right)^{\varphi} \left(F^t_{t,t} - F_{o,t}\right)^{1-\varphi}, \tag{10}$$

[9] An 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 $L_s(f)$.

where φ is the relative bargaining power of households, $U_{o,t}$ is the threat point for the households and $F_{o,t}$ is the threat point of the firm. The threat point is the payoff when there is disagreement during the period (i.e., strike or lockout). The per-period payoff of the firm when there is a strike is assumed to be zero. 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 resuming bargaining next periods also enters respective parties threat point. This 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).

The main difference in the wage bargain between our 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 (2007) and others, is that the outside option of a household does not depend upon aggregate conditions directly.[10] That is, the attachment of a worker to a firm remains even under unemployment. Indirectly, however, aggregate conditions will affect workers 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 the wage bargain has recently been questioned by Hall and Milgrom (2008).[11] It is interesting to note, though, that the wage-setting relationship we derive is very similar to that of a search model.

Using the family payoff (8) and budget constraint (9), the value of not having a conflict for the household attached to firm f is

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

where

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

To derive the surpluses in (10), we let,

$$\begin{aligned} \Upsilon_{t+k,t+k+j}^{t} &= L_{t+k,t+k+j}^{t}\left(f\right)\left(\left(1+\tau_w\right)\frac{\left(\bar{\pi}\right)^{k+j}W_t\left(f\right)}{P_{t+k+j}}\right) + \left(1 - L_{t+k,t+k+j}^{t}\left(f\right)\right)b \\ &\quad -\frac{V\left(L_{t+k,t+k+j}^{t}\left(f\right), Z_{t+k+j}\right)}{u_{C,t+k+j}} \end{aligned} \tag{13}$$

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

[11] The 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.

denote per-period utility.[12] Then we can write

$$U_{t,t}^{t}=\Upsilon_{t,t}^{t}+\alpha_{w}\beta E_{t}\frac{u_{C,t+1}}{u_{C,t}}\left(\alpha U_{t,t+1}^{t}+\left(1-\alpha\right)U_{t+1,t+1}^{t}\right)+\left(1-\alpha_{w}\right)\beta E_{t}\frac{u_{C,t+1}}{u_{C,t}}U_{t+1,t+1}^{t+1}. \tag{14}$$

In the next period, wages may or may not be renegotiated. In case 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 $U_{t,t+1}^{t}$. In case 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.

In case the firm and workers renegotiate the wage, bargaining takes place according to the non-cooperative Rubinstein-Ståhl model. In case there is disagreement, there is a conflict during the remainder of the period, whereafter negotiations continue in the next period. The payoff in case there is a conflict is then

$$U_{o,t}=\Upsilon_{o,t}+\beta E_{t}\frac{u_{C,t+1}}{u_{C,t}}U_{t+1,t+1}^{t+1}, \tag{15}$$

where

$$\Upsilon_{o,t}=b-\frac{v\left(0,Z_{t+k+j}\right)}{u_{C,t+k+j}}. \tag{16}$$

Some algebra establishes that

$$\begin{aligned}
U_{t,t}^{t}-U_{o,t} = {} & \Upsilon_{t,t}^{t}-\Upsilon_{o,t}+\sum_{k=1}^{\infty}\left(\alpha_{w}\alpha\beta\right)^{k}E_{t}\frac{u_{C,t+k}}{u_{C,t}}\left(\Upsilon_{t,t+k}^{t}-\Upsilon_{t+1,t+k}^{t}\right)\\
&+\alpha_{w}\beta\sum_{k=0}^{\infty}\left(\alpha_{w}\alpha\beta\right)^{k}E_{t}\frac{u_{C,t+k+1}}{u_{C,t}}\left(\Upsilon_{t+1,t+k+1}^{t}-\Upsilon_{t+1,t+k+1}^{t+1}\right)\\
&+\left(1-\alpha\right)\sum_{k=2}^{\infty}\left(\alpha_{w}\beta\right)^{k}\sum_{j=0}^{\infty}\left(\alpha_{w}\alpha\beta\right)^{j}E_{t}\frac{u_{C,t+j+k}}{u_{C,t}}\left(\Upsilon_{t+k,t+j+k}^{t}-\Upsilon_{t+k,t+j+k}^{t+1}\right).
\end{aligned} \tag{17}$$

Now consider the firm. Since values have the same structure as for households, we have

$$\begin{aligned}
F_{t,t}^{t} &= \phi_{t,t}^{t}+\alpha_{w}\beta E_{t}\frac{u_{C,t+1}}{u_{C,t}}\left(\alpha F_{t,t+1}^{t}+\left(1-\alpha\right)F_{t+1,t+1}^{t}\right)\\
&\quad+\left(1-\alpha_{w}\right)\beta E_{t}\frac{u_{C,t+1}}{u_{C,t}}F_{t+1,t+1}^{t+1},
\end{aligned} \tag{18}$$

$$F_{o,t} = 0+\beta E_{t}\frac{u_{C,t+1}}{u_{C,t}}F_{t+1,t+1}^{t+1}, \tag{19}$$

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

[12] The 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.

t, is denoted as

$$\phi_{t,t+k+j}^{t} = (1+\tau)\,\frac{P_{t+k}^{o}(f)}{P_{t+k+j}}Y_{t+k+j}(f) - tc\left(\frac{W_t(f)}{P_{t+k+j}}, Y_{t+k+j}(f)\right). \tag{20}$$

An expression similar to (17) can be derived for $F_{t,t}^{t} - F_{o,t}$ (see the technical appendix for details).

The first-order condition of the Nash product (10) is

$$\varphi\left(F_{t,t}^{t} - F_{o,t}\right)\frac{\partial U_{t,t}^{t}}{\partial W(f)} + (1-\varphi)\left(U_{t,t}^{t} - U_{o,t}\right)\frac{\partial F_{t,t}^{t}}{\partial W(f)} = 0. \tag{21}$$

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. [13]

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. $\overline{Y}(f) = \overline{Y}$, using the same (constant) quantity of labor and all firms demand the same amount of labor, i.e. $\overline{L}(f) = \overline{L}$. Moreover, we will have that $\overline{C} = \overline{Y}$ and that $B = 0$. Also, M and P are constant. Finally, note that under the tax-scheme outlined above, eliminating 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

[13] Remember, that if the union has all the bargaining power it will use it's monopoly power and set the wage inefficiently high, on the other hand, if the firm has all the bargaining power it will set inefficiently low wages by using it's monopsony power.

gives the following system of equations (see the technical appendix for details)

$$
\begin{aligned}
\hat{x}_t &= E_t\left(\hat{x}_{t+1} - \frac{1}{\rho_C}\left(\widehat{i}_t - \hat{\pi}_{t+1} - \widehat{r}_t^*\right)\right), && (22)\\
\hat{w}_t &= \hat{w}_{t-1} + \hat{\pi}_t^{\omega} - \hat{\pi}_t, && (23)\\
\hat{\pi}_t &= \beta E_t\hat{\pi}_{t+1} + (1-\gamma)\left(\hat{\pi}_t^{\omega} - \beta E_t\hat{\pi}_{t+1}^{\omega}\right) + \Pi\left(\hat{w}_t - \hat{w}_t^*\right) + \frac{\gamma}{1-\gamma}\Pi\hat{x}_t, && (24)\\
\hat{\pi}_t^{\omega} &= \beta E_t\hat{\pi}_{t+1}^{\omega} - \Omega_x\hat{x}_t - \Omega_w\left(\hat{w}_t - \hat{w}_t^*\right) && (25)\\
&\quad -\Omega_n^{+1}\left(E_t\hat{\pi}_{t+1}^{\omega} - \beta E_t\hat{\pi}_{t+2}^{\omega}\right) - \Omega_x^{+1}E_t\hat{x}_{t+1} - \Omega_w^{+1}E_t\left(\hat{w}_{t+1} - \hat{w}_{t+1}^*\right),
\end{aligned}
$$

where $1/\rho_C$ is the intertemporal elasticity of substitution in consumption and Ω_x, Ω_w, Ω_n^{+1}, Ω_x^{+1} and Ω_w^{+1} are defined in appendix A and

$$
\Pi = (1-\alpha_w\alpha\beta)\frac{1-\alpha_w\alpha}{\alpha_w\alpha}\frac{1-\gamma}{1-\gamma+\sigma\gamma}. \tag{26}
$$

Equation (22) 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 $(\widehat{i}_t - \hat{\pi}_{t+1} - \widehat{r}_t^*)$, where $\widehat{i}_t$ denotes the log-deviation of the nominal interest rate from steady state and $\widehat{r}_t^*$ 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 (23), 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 (22) and the evolution of real wages (23) 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 (24) 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 wage-changing firms among the firms that change prices is different from the economy-wide average, which then motivates the "correction term" $(1-\gamma)\left(\hat{\pi}_t^{\omega} - \beta E_t\hat{\pi}_{t+1}^{\omega}\right)$. Thus, the real-wage effect in (24) has been decomposed into an aggregate real-wage change $(\hat{w}_t - \hat{w}_t^*)$ effect and a wage-inflation $\left(\hat{\pi}_t^{\omega} - \beta E_t \hat{\pi}_{t+1}^{\omega}\right)$ effect.[14]

Equation (25) is the wage-setting curve. This expression is similar, but not identical to the wage setting relationship in the EHL and FSC models. In the EHL and FSC models the $\hat{\pi}_t^{\omega}$ equation involves only the first row of (25) and with different values for Ω_x and Ω_w.[15] The terms multiplied by Ω_n^{+1}, Ω_x^{+1} and Ω_w^{+1} stem from that expected future conditions affect the outside options in the bargaining problem. Note however that Ω_n^{+1}, Ω_x^{+1} and Ω_w^{+1} are all zero in equation (25) when the workers have all the bargaining power, i.e. $\varphi = 1$. The reason is that, since the firm receives a strictly positive steady-state profit (implying $F_{t,t}^t > F_{o,t}$) even when the workers have all the bargaining power, the wage is determined by maximizing worker payoff without constraints. Thus, the wage is chosen to maximize (17) and it is easy to see that $\frac{\partial U_{t,t}^t}{\partial W(f)}$ only depend on current wages.[16]

The wage-setting curve is similar in structure to models with a search-matching framework on the labor market. It is easy to show, by using (23) and (24) in (25), 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.

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, the special case when the workers have all the bargaining power is illustrative, because a direct comparison of the Phillips Curve in the FSC and the FSL/FSC models can be made. In the FSC model the Phillips Curve is

$$\hat{\pi}_t = \beta E_t \hat{\pi}_{t+1} + \Pi\left(\hat{w}_t - \hat{w}_t^*\right) + \frac{\gamma}{1-\gamma}\Pi \hat{x}_t \tag{27}$$

and, in the FSL/FSC model, using that $\varphi = 1$ implies $\Omega_n^{+1} = \Omega_w^{+1} = \Omega_x^{+1} = 0$ and eliminating the

[14] 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).

[15] If $b = 0$, $\varphi = 1$ and that 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).

[16] When the union has all bargaining power, the wage is determined by solving

$$\max\left(U_{t,t}^t - U_{o,t}\right)$$

subject to

$$F_{t,t}^t - F_{o,t} \geq 0.$$

The first-order condition is

$$\frac{\partial U_{t,t}^t}{\partial W(f)} - \lambda\frac{\partial F_{t,t}^t}{\partial W(f)} = 0,$$

By inspecting expression (17), it is easy to see that $\frac{\partial U_{t,t}^t}{\partial W(f)}$ only depend on current wages. A similar argument establishes that $\frac{\partial F_{t,t}^t}{\partial W(f)}$ only depend on the current wage contract. However, through λ, in case the constraint is binding, future wage contracts affect the current wage contract via threat points. However, since firms receive a strictly positive steady-state profit (i.e., $\tau\bar{Y}$), we have $F_{t,t}^t > F_{o,t}$ and hence the wage is determined by $\frac{\partial U_{t,t}^t}{\partial W(f)} = 0$, implying that Ω_n^{+1}, Ω_x^{+1} and Ω_w^{+1} are all zero.

wage inflation terms in (24) by using (25), is

$$\hat{\pi}_t = \beta E_t \hat{\pi}_{t+1} + (\Pi - (1-\gamma)\,\Omega_w)\,(\hat{w}_t - \hat{w}_t^*) + \left(\frac{\gamma}{1-\gamma}\Pi - (1-\gamma)\,\Omega_x\right)\hat{x}_t. \tag{28}$$

Thus, the responsiveness of inflation to shocks, i.e., innovations to $\hat{w}_t^*$ changes by $(1-\gamma)\,\Omega_w$. This is caused by the indirect effects via wage setting, where an increase in the real wage gap gap leads to changes in wage inflation.[17] Using the baseline calibration presented in table 1 below, except for setting φ equal to unity, 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.[18] As we will see below, these effects remain 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

$$E_t \sum_{t=0}^{\infty} \beta^t \left(u\,(C_t) - \int_0^1 V\,(L_t\,(h))\,dh\right). \tag{29}$$

Proceeding as in Rotemberg and Woodford (1997), EHL and others, we take a second-order approximation to (29) 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,

$$E_t \sum_{t=0}^{\infty} \beta^t \left(\theta_x\,(\hat{x}_t)^2 + \theta_\pi\,(\hat{\pi}_t)^2 + \theta_{\pi^\omega}\,(\hat{\pi}_t^\omega)^2\right), \tag{30}$$

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 A 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

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

[18] When comparing with 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.

and wages. Non-degenerate distributions of prices and wages implies 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.

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 is used 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 (30). Here, we focus on the commitment case.[19] An 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).[20]

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,

$$\widehat{i}_t = (1-\rho_I)\left(\gamma_\pi \hat{\pi}_t + \gamma_x \hat{x}_t\right) + \rho_I \widehat{i}_{t-1}. \tag{31}$$

To close the general equilibrium system (22)-(25), we eliminate the nominal interest rate from the Euler equation (22) using the simple rule (31) and the real interest rate using the corresponding flexible-price Euler equation. This condition, together with the three constraints (23) to (25), 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 (30) subject to the restrictions (22)-(25). 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

[19] The discretionary case is analyzed in appendix B.

[20] The steady-state values of the Lagrange multipliers for the forward-looking variables are zero. When imposing this initial value when solving for the timeless optimal policy, the solution is identical to the commitment solution.

from maximizing (30) and from the equations (23)-(25) and the shock process for $\hat{w}_t^*$. To solve for the commitment solution, we rewrite the system of constraints (23)-(25) and the shock process appropriately and then follow the method described in Söderlind (1999) (see the technical appendix for details).[21]

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

$$\hat{w}_t^* = \eta \hat{w}_{t-1}^* + \varepsilon_t, \tag{32}$$

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

For our numerical exercises, we assume that

$$u(C_t) = \frac{1}{1-\chi_C}\left(C_t - \bar{Q}\right)^{1-\chi_C}, \tag{33}$$

and that

$$v(H_t) = -\frac{1}{1-\chi_L}\left(1 - H_t - \bar{Z}\right)^{1-\chi_L}, \tag{34}$$

where $H_t = \overline{H}$ 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.[22] Moreover, we parametrize the disutility of labor supply as

$$\vartheta(j) = j^{\varsigma}. \tag{35}$$

The calibration of the deep parameters are presented in Table 1. To find the steady state of the model, we set the labor share $1-\gamma$ to 2/3, the employment rate $\bar{L}$ to 0.95, $\overline{A} = 1$ and $\overline{H} = 0.27$, $\bar{Z} = 0.03$. Thus, $\overline{H}$ and $\overline{Z}$ 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 assuming values for the Frisch labor-supply elasticity, $1/\rho_L$, and the intertemporal elasticity of substitution in consumption, $1/\rho_C$.[23] This then lets us determine χ_C and ς, as well as all other

[21] Note 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).

[22] In 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.

[23] The (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

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) (referred to by Kuester, 2007) and slightly larger than the estimate of 0.16 reported by Rotemberg and Woodford (1997), but just below the estimate of 0.23 reported by Giannoni and Woodford (2005).[24] 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). Letting

Table 1: Baseline Calibration of the Model

Deep Parameters		Derived Parameters	
α	5/6	χ_C	0.537
α_w	3/4	ς	20.07
β	0.99	Π	0.0762
γ	1/3	Π_W	0.229
χ_L	1.5	Ω_x	-0.0204
σ	4	$\Omega_x^{EHL} = \Omega_x^{FSC}$	-0.0318
σ_w	4	Ω_x^{+1}	0.00113
$b/\bar{w}$	0.6	Ω_w	0.0858
φ	0.5	$\Omega_w^{EHL} = \Omega_w^{FSC}$	0.00209
η	0.95	Ω_w^{+1}	-0.00538
σ_ϵ	0.01	Ω_n^{+1}	-0.0627
ρ_C	0.2	$\theta_x = \theta_x^{EHL} = \theta_x^{FSC}$	8.02
ρ_L	-10	θ_π	562.7
γ_π	1.5	θ_π^{EHL}	8.932
γ_x	0.5	θ_π^{FSC}	26.8
ρ_I	0.8	θ_{π^ω}	936.9
		$\theta_{\pi^\omega}^{EHL} = \theta_{\pi^\omega}^{FSC}$	650.6

d_p and d_w denote the duration of price and wage contracts, respectively, we have $d_p = 1/(1-\alpha_w\alpha)$ and $d_w = 1/(1-\alpha_w)$. 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. 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, $\chi_L(=1.5)$, $\sigma(=4)$, $\sigma_w(=4)$ 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. We set the bargaining power $\varphi = 0.5$, implying symmetrical bargaining.

elasticity of substitution in consumption, ρ_C, is defined as $-\frac{\bar{u}_{CC}\bar{C}}{\bar{u}_C}$.

[24]This is the estimate for their model without habit persistence.

In table 1, we also present the values of the derived coefficients for the loss function. As can be seen, 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 (i.e., 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.

Not only the loss function is modified, though, when introducing firm-specific labor. Also, private sector behavior changes dramatically. Remember, that in the wage-setting curve in the EHL and the FSC framework, we have $\Omega_x^{+1} = \Omega_w^{+1} = \Omega_n^{+1} = 0$. Moreover, 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.[25] Since some households do not change wages, higher wages have large negative effects on labor demand leading to a small response of wage inflation. However, the coefficients in front of the output gap remains fairly similar across models (Ω_x, Ω_x^{EHL} and Ω_x^{FSC}, respectively).

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, consistently with the empirical literature.

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 (31) and plot impulse responses in the two cases, using 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. Secondly, we analyze the consequences of optimal policy in the two models.

7.1 Impulse Responses Under the Simple Rule

In Figure 1, 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 (31).

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

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

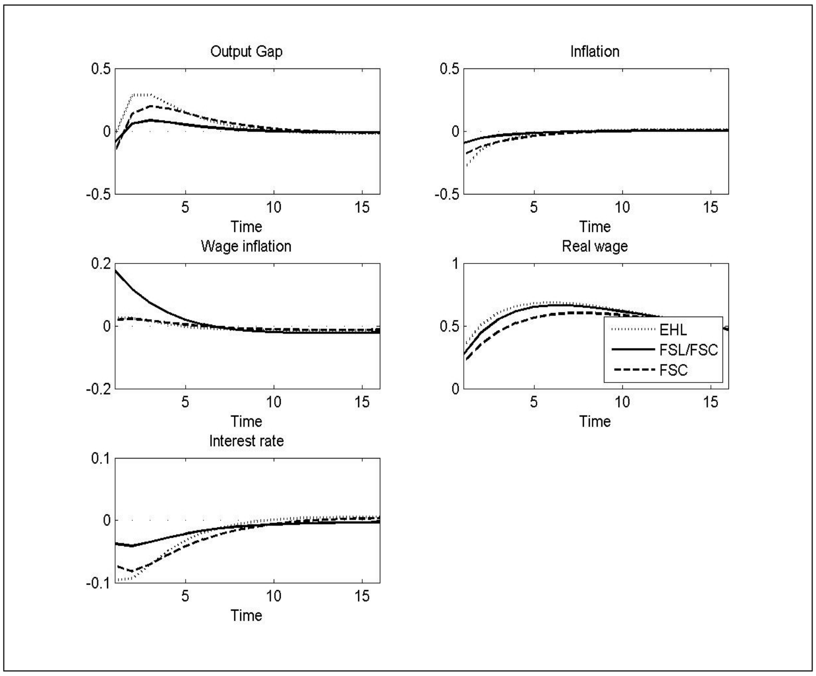

Figure 1: Impulse responses to a one-percent innovation to $\hat{w}_t^*$ when the nominal interest rate is governed by the simple rule.

the policy rate in order to increase the real wage. This is achieved by keeping inflation lower than wage inflation and this is also what the simple rule implies. However, given the AR(1) structure of the 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 $(\hat{\pi}_t^{\omega} - \hat{\pi}_t)$ 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 1, we see that the wage-inflation response is substantially higher in the model with firm-specific labor. This results stems from the changes in the wage-setting curve when introducing firm specificity in labor. As can also be seen in figure 1, the initial inflation response is almost doubled in the EHL model with firm-specific capital and tripled in the EHL model with flexible capital as compared to the model with firm-specific capital and labor. The reason for this stems, in part, from the counteracting wage-inflation pressure on inflation working through the "correction term" $(1-\gamma)\left(\hat{\pi}_t^{\omega} - \beta E_t \hat{\pi}_{t+1}^{\omega}\right)$ in the Phillips-curve (24). This leads to a lower inflation response in the model with firm-specific capital and labor. The remaining part of the difference between the models stems from the change of the shape of the wage-setting curve, and when comparing the EHL and FSC models from the change in the Π coefficient in the price-setting curve.

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 1, 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 decision is of crucial importance for the inflation response, as can be seen from figure 2. 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 (2007), then inflation hardly responds at all to shocks (a substantial damped response to inflation is also obtained under optimal policy under perfect synchronization, see section 7.4).[26] This indicates that allowing for imperfect synchronization between price- and wage decisions is important when studying effects of firm-specific labor. The reason why 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 is due to firms that 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, inflation response little to productivity. In contrast, when there are firms that adjust only prices, the productivity effect through marginal costs have a large effect on prices, since wages are unchanged, leading to a larger negative response in inflation to a positive productivity shock.

Since the model derived here, in contrast to the EHL and the FSC framework, includes unemployment, we have also plotted the impulse responses of unemployment to a real-wage shock in figure 2. As is evident from figure 2, unemployment (and also the output gap) are stabilized much more in the case with perfectly synchronized price and wage changes.[27] In the baseline calibration, unemployment will be closely related to the negative of the output gap.[28] In line with empirical evidence (see e.g. Galí (1999), Alexius and Carlsson (2005), Basu, Fernald, and Kimball (2007)), we find that that labor input falls initially in response to a technology improvement.

[26] See 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 duration is six quarters and price duration four as in the baseline calibration of Christoffel, Costain, de Walque, Kuester, Linzert, Millard, and Pierrard, 2009, the impulse responses remain similar as compared to our baseline calibration.

[27] Note that the steady-state unemployment rate is equal to five percent in the model. The maximum response of about -4 percent in the baseline case thus translates into a decrease of the unemployment rate down to 4.8 percent.

[28] In the technical appendix, we show that unemployment can be expressed as $\hat{u}_t = -\frac{\bar{L}}{1-\bar{L}}\left(\frac{1}{1-\gamma}\hat{x}_t + \frac{(1-\rho_C)}{\rho_C-\rho_L}\hat{w}_t^*\right)$. The coefficient on $\hat{w}_t^*$ will be fairly small in the baseline calibration.

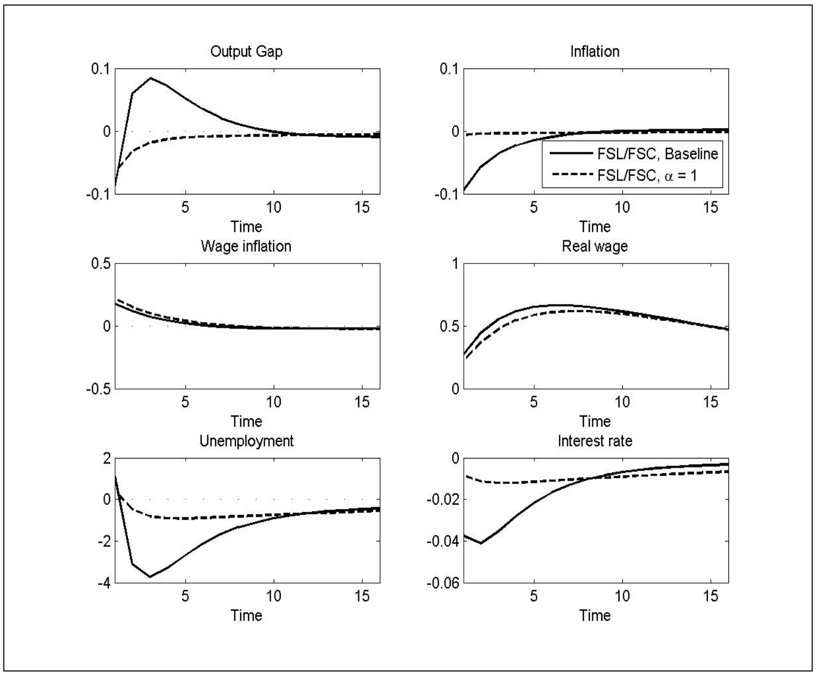

Figure 2: Impulse responses to a one-percent innovation to $\hat{w}_t^*$ when the nominal interest rate is governed by the simple rule when $\alpha = 5/6$ and $\alpha = 1$, respectively.

7.2 Empirical Impulse Responses

In this section 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.[29,30] 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 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

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

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

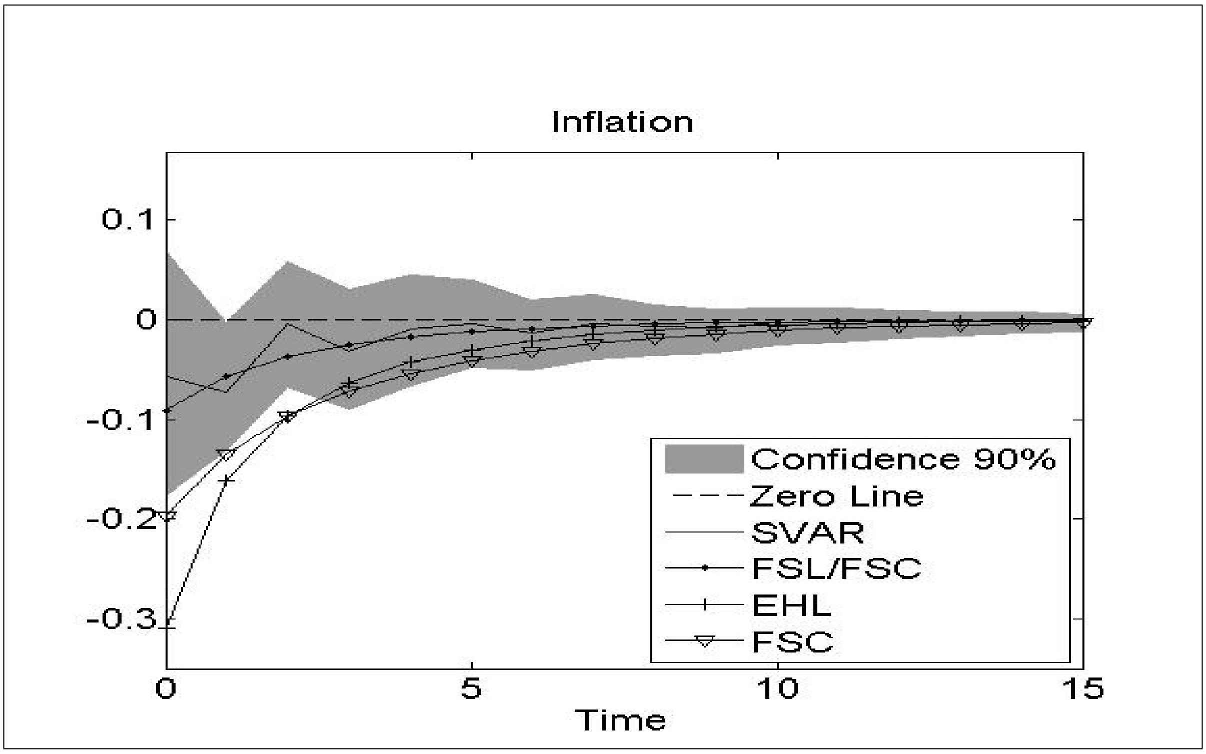

Figure 3: Impulse responses to a one-percent permanent innovation to technology in the models under the simple rule and in the data. Confidence bands are based on 999 bootstrap replications. SVAR line corresponds to the median response in the bootstrap distribution.

plausibly argue that systematic policy has remained stable.

In figure 3 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 indicate a moderate initial response of inflation of about 0.06 percent and then tending back towards zero. Figure 3 also report 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.[31] In order to mimic the behavior to a permanent shock we set η to 0.9999 when computing theoretical impulse responses in this section. As seen in the figure 3, 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 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 4 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

[31]Note that the natural real wage moves one-to-0.97 with the technology shock in the models above

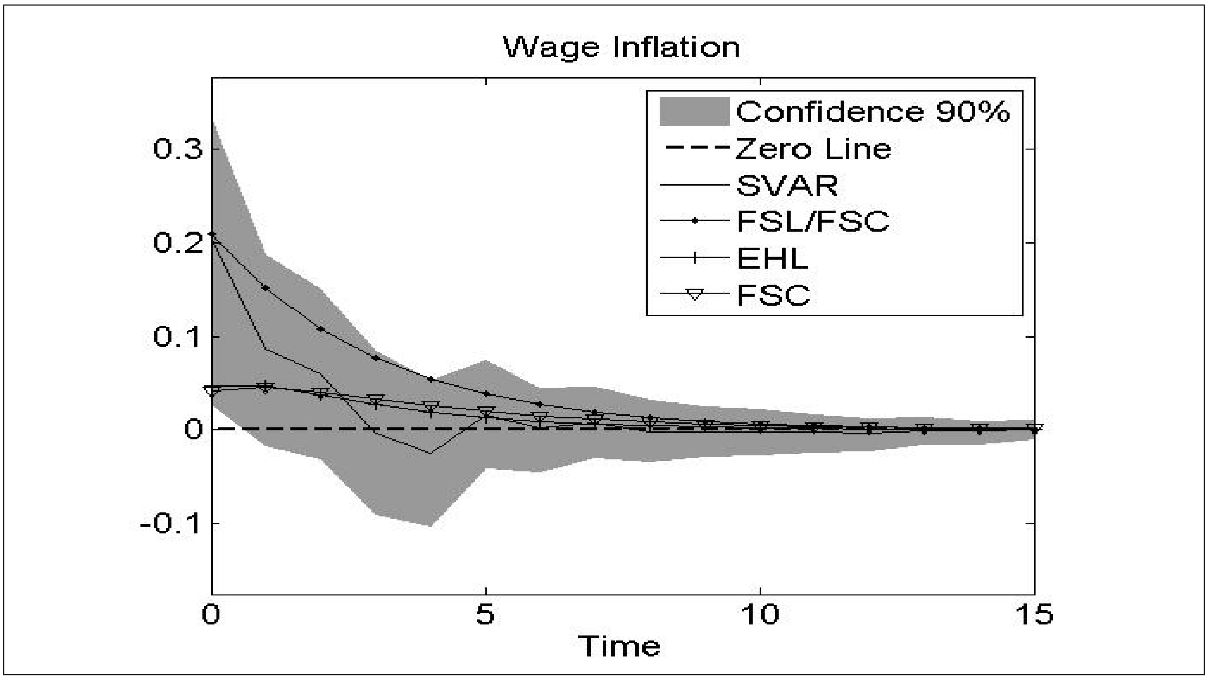

Figure 4: Impulse responses to a one-percent permanent innovation to technology in the models under the simple rule and in the data. Confidence bands are based on 999 bootstrap replications. SVAR line corresponds to the median response in the bootstrap distribution.

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 implies 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 5, we plot the impulse responses for the three models under the optimal policy. As can be seen in the figure, the qualitative difference between the simple-rule responses and the optimal-policy responses lies in the output-gap and the interest-rate responses. The output-gap response is substantially changed in all three models. The hump-shape vanishes under optimal policy in the models with mobile labor and the output gap hardly responds at all to the shock. With firm-specific labor, the response is still hump-shaped but now the output gap decreases significantly, in contrast to the simple rule. Optimal policy also implies a much more aggressive response of the interest rate in

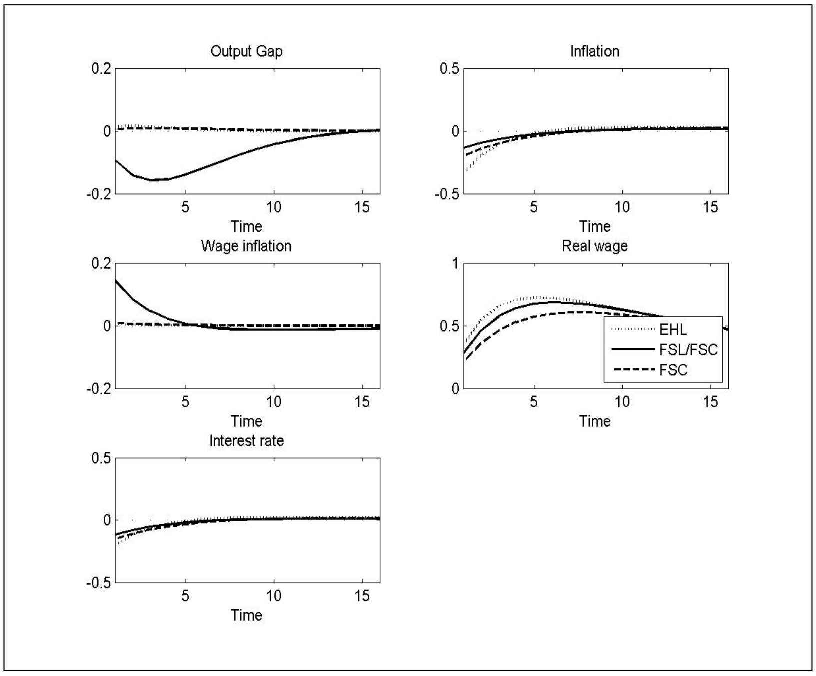

Figure 5: Impulse responses to a one-percent innovation to $\hat{w}_t^*$ under optimal policy.

all models.

The inflation response is again substantially smaller in the FSL/FSC model, as compared to the other two models. As under the simple rule, 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 on optimal policy from private-sector behavior. Again, as discussed above, wage inflation hardly responds at all in the EHL and FSC models to innovations in the real-wage gap, having a major effect on the optimal choices of the central bank.

7.4 Robustness

The results presented above are rather insensitive to variations in a number of parameters (see appendix B 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 φ has only small effects on impulse responses under both the simple rule, as well as under optimal policy. Thus, we do not see a strong impact on the equilibrium dynamics from varying the parameters related to labor-market institutions. Finally, under both types of 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 becomes 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), but not nearly as much. Furthermore, using a family construct to achieve consumption insurance in the EHL model instead of the original setup of Erceg, Henderson, and Levin (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 bargained over between firms and 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 firm-specific factors for the inflation response, we find that the price- and wage-setting relationships that arise under firm-specific labor 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 evidence on the inflation and wage-inflation response derived from a SVAR.

Further, we find that allowing for non-synchronized wage and price setting has important effects on the inflation response. Especially, when price and wage changes are completely synchronized, as in Kuester (2007), price-setting behavior is very much altered and inflation hardly responds at all to productivity shocks.

The model-consistent welfare measure derived in the paper indicates that the main effect of introducing firm-specific labor is that the loss associated with inflation variability increases dramatically. This is due that price dispersion lead 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, we find that the output-gap responses differs substantially between policies within models. Moreover, 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 Derived Parameters

In the technical appendix we derive, letting

$$\begin{aligned}
\varepsilon_L &= \frac{\partial L_t(f)}{\partial W(f)} \frac{W(f)}{L_t(f)} = -\sigma \frac{1}{1-\gamma}, && (36)\\
\Pi_1 &= (1-\alpha_w \beta) \frac{1-\alpha_w}{\alpha_w}, && (37)
\end{aligned}$$

the coefficients in the wage setting curve (25) as

$$\begin{aligned}
\Omega_x &= \Pi_1 \frac{\Phi_x}{\Phi_n}, \\
\Omega_w &= \Pi_1, \\
\Omega_n^{+1} &= \frac{\Phi_n^{+1}}{\Phi_n}, \qquad (38)\\
\Omega_x^{+1} &= \Pi_1 \frac{\Phi_x^{+1}}{\Phi_n}, \\
\Omega_w^{+1} &= \Pi_1 \Omega_n^{+1}.
\end{aligned}$$

where

$$\begin{aligned}
\Phi_n &= \varphi \frac{\bar{w}\bar{L}}{W_t(f)} \varepsilon_L \left(1 + \frac{b}{\bar{w}} - \frac{\sigma}{1-\gamma} \frac{1}{1+\sigma\frac{\gamma}{1-\gamma}} \rho_L\right) + (1-\varphi) \frac{1}{1-\alpha_w\beta} \frac{\bar{w}\bar{L}}{W_t(f)} \\
&\quad \times \left(\frac{b}{\bar{w}} - \varepsilon_L \frac{1}{1+\sigma\frac{\gamma}{1-\gamma}} + \left(\frac{V\left(\bar{L},\bar{Z}\right)}{\bar{u}_C\bar{w}\bar{L}} - \frac{V\left(0,\bar{Z}\right)}{\bar{u}_C\bar{w}\bar{L}}\right) \frac{1-\sigma}{1+\sigma\frac{\gamma}{1-\gamma}}\right) \frac{(1-\sigma)}{1+\frac{\gamma}{1-\gamma}\sigma}, \qquad (39)\\
\Phi_n^{+1} &= -(1-\varphi) \frac{\alpha_w\beta}{1-\alpha_w\beta} \frac{\bar{w}\bar{L}}{W_t(f)} \\
&\quad \times \left(\frac{b}{\bar{w}} - \varepsilon_L \frac{1}{1+\sigma\frac{\gamma}{1-\gamma}} + \left(\frac{V\left(\bar{L},\bar{Z}\right)}{\bar{u}_C\bar{w}\bar{L}} - \frac{V\left(0,\bar{Z}\right)}{\bar{u}_C\bar{w}\bar{L}}\right) \frac{1-\sigma}{1+\sigma\frac{\gamma}{1-\gamma}}\right) \frac{(1-\sigma)}{\left(1+\frac{\gamma}{1-\gamma}\sigma\right)},
\end{aligned}$$

and

$$
\begin{aligned}
\Phi_x &= \varphi \frac{\bar{w}\bar{L}}{W_t(f)} \varepsilon_L \left(\rho_L \frac{1}{1-\gamma} \frac{1}{1+\sigma\frac{\gamma}{1-\gamma}} - \rho_C \right) + (1-\varphi) \frac{1}{1-\alpha_w \beta} \frac{(1-\sigma)}{1+\frac{\gamma}{1-\gamma}\sigma} \frac{\bar{w}\bar{L}}{W_t(f)} \\
&\times \left(\left(\frac{V\left(\bar{L},\bar{Z}\right)}{\bar{u}_C \bar{w}\bar{L}} - \frac{\bar{V}\left(0,\bar{Z}\right)}{\bar{u}_C \bar{w}\bar{L}} \right) \left(\frac{1}{1-\gamma} \frac{1}{1+\sigma\frac{\gamma}{1-\gamma}} - \rho_C \right) - \frac{1}{1-\gamma} \frac{1}{1+\sigma\frac{\gamma}{1-\gamma}} \right), \qquad (40) \\
\Phi_x^{+1} &= -(1-\varphi) \frac{\alpha_w \beta}{1-\alpha_w \beta} \frac{(1-\sigma)}{1+\frac{\gamma}{1-\gamma}\sigma} \frac{\bar{w}\bar{L}}{W_t(f)} \\
&\times \left(\left(\frac{V\left(\bar{L},\bar{Z}\right)}{\bar{u}_C \bar{w}\bar{L}} - \frac{\bar{V}\left(0,\bar{Z}\right)}{\bar{u}_C \bar{w}\bar{L}} \right) \left(\frac{1}{1-\gamma} \frac{1}{1+\sigma\frac{\gamma}{1-\gamma}} - \rho_C \right) - \frac{1}{1-\gamma} \frac{1}{1+\sigma\frac{\gamma}{1-\gamma}} \right),
\end{aligned}
$$

In the technical appendix we derive the following parameters for the welfare gap expression (30)

$$
\begin{aligned}
\theta_x &= \frac{\Lambda^* \bar{C}}{2} = \frac{\bar{u}_C \bar{C}}{2} \left(-\rho_C + \rho_L \frac{1}{1-\gamma} - \frac{\gamma}{1-\gamma} \right), \\
\theta_\pi &= -\left(\bar{u}_C \bar{C} \frac{1}{2} \sigma^2 \left(\frac{1-\sigma}{\sigma} + \frac{1-\rho_L}{1-\gamma} \right) \right) \frac{1}{\Pi_W}, \qquad (41) \\
\theta_{\pi^\omega} &= -\left(\bar{u}_C \bar{C} \frac{1}{2} \sigma^2 \left(\frac{1-\sigma}{\sigma} + \frac{1-\rho_L}{1-\gamma} \right) \right) \left(-\frac{1}{\Pi_W} + \frac{1}{\Pi_1} \right),
\end{aligned}
$$

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

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

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

$$
\begin{aligned}
\Omega_w^{EHL} &= \Omega_w^{FSC} = \frac{\Pi_1}{1-\rho_L \sigma_w}, \qquad (42) \\
\Omega_x^{EHL} &= \Omega_x^{FSC} = \Omega_w^{EHL} \left(\rho_C - \rho_L \frac{1}{1-\gamma} \right).
\end{aligned}
$$

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

$$
\hat{\pi}_t = \beta E_t \hat{\pi}_{t+1} + \Pi_W (\hat{w}_t - \hat{w}_t^*) + \frac{\gamma}{1-\gamma} \Pi_W \hat{x}_t \qquad (43)
$$

and, in the FSC model

$$
\hat{\pi}_t = \beta E_t \hat{\pi}_{t+1} + \Pi (\hat{w}_t - \hat{w}_t^*) + \frac{\gamma}{1-\gamma} \Pi \hat{x}_t. \qquad (44)
$$

Finally, the loss function parameters are

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

B Robustness

In this appendix we study the robustness of the results presented above in detail. First we see how impulse responses changes when relying on discretionary policy instead of the commitment policy. The impulse responses to a one-percent innovation to the natural real wage $\hat{w}_t^*$ for the two different policies are plotted in figure 6. As can be seen in figure 6, the inflation and wage inflation response is

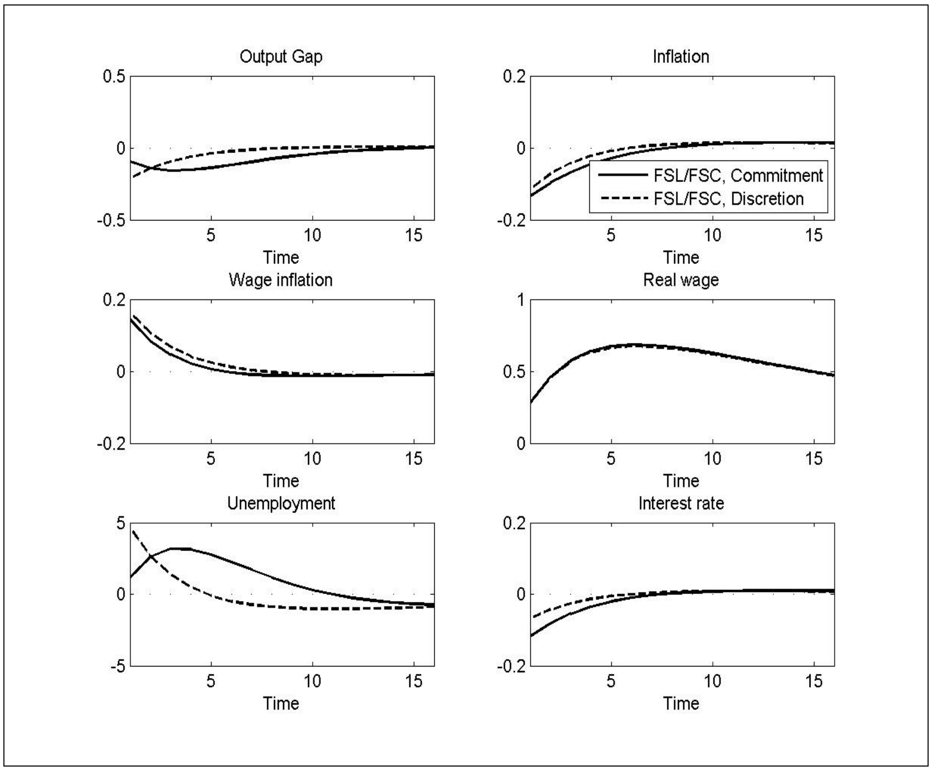

Figure 6: Impulse responses to a one-percent innovation to $\hat{w}_t^*$ under discretion and commitment.

fairly similar. The differences lies in the medium-term response for the output gap and unemployment. This is due to that, in the commitment solution, the central bank use its influence over expectations in order to stabilize wage-inflation variation, which, together with inflation, is a key cost component in the loss function (30), 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.

Next, we turn to robustness exercises where we vary key parameters in order to explore the sensitivity of the results presented above. In figures 7 to 11 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 (31).[32]

Overall, the results are rather insensitive to perturbations of the parameters around the baseline

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

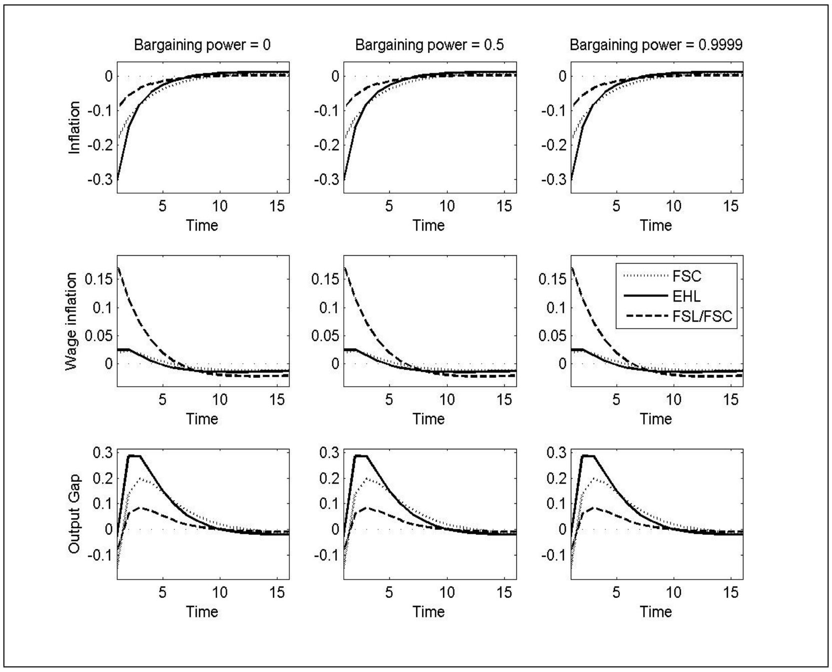

Figure 7: Impulse responses to a one-percent innovation to $\hat{w}_t^*$ when the nominal interest rate is governed by the simple rule in our and the EHL model for different values of the barganing power.

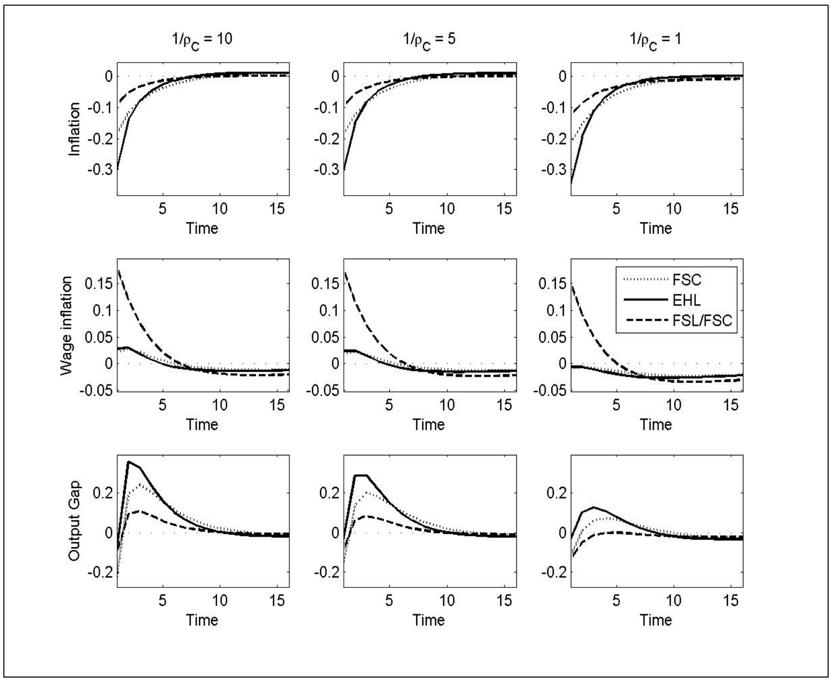

Figure 8: Impulse responses to a one-percent innovation to $\hat{w}_t^*$ when the nominal interest rate is governed by the simple rule for different values of the intertemporal elasticity of substitution in consumption.

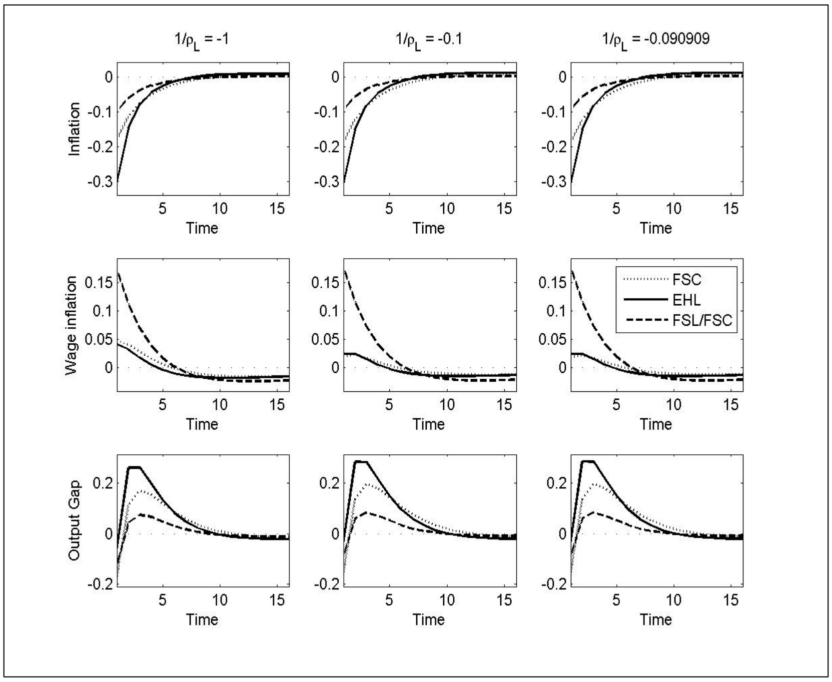

Figure 9: Impulse responses to a one-percent innovation to $\hat{w}_t^*$ when the nominal interest rate is governed by the simple rule for different values of the Frisch labor-supply elasticity.

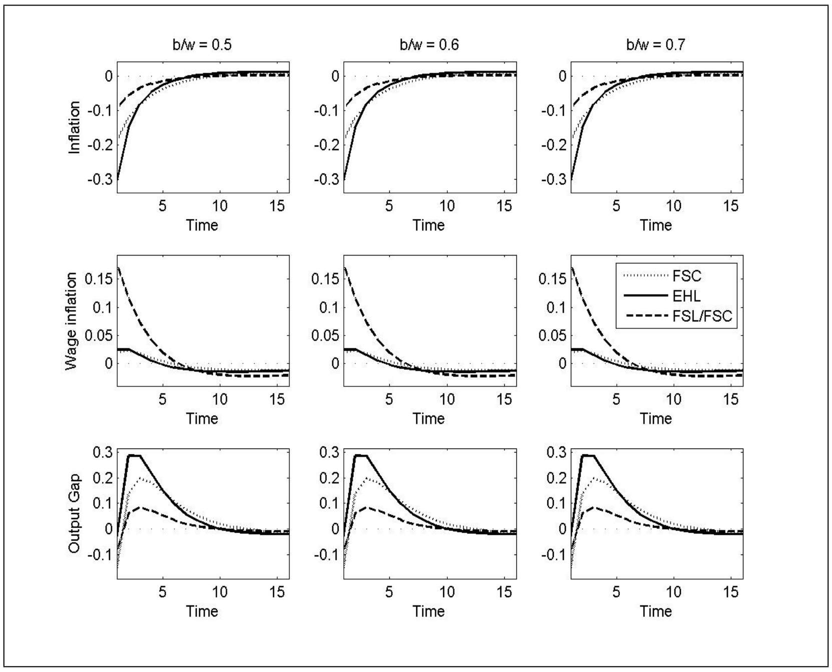

Figure 10: Impulse responses to a one-percent innovation to $\hat{w}_t^*$ when the nominal interest rate is governed by the simple rule for different values of the replacement rate.

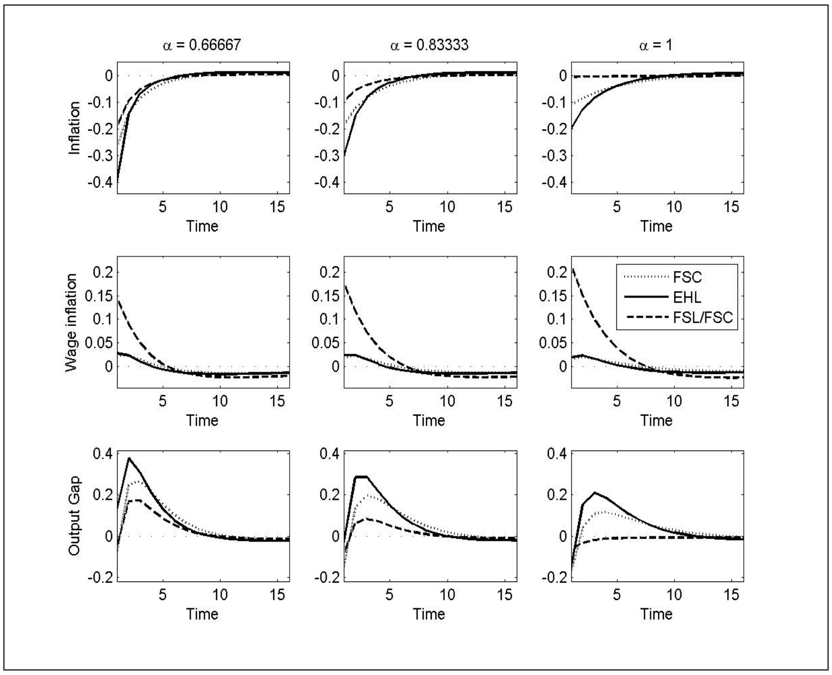

Figure 11: Impulse responses to a one-percent innovation to $\hat{w}_t^*$ when the nominal interest rate is governed by the simple rule for different values of the price adjustment probability α.

calibration. We still see a substantial difference in the initial inflation response to a real-wage shock. Also, as can be seen from figure 11, varying the price adjustment probability have 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 2. However, figure 11 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 due to that 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).

Finally, in figures 12 to 16, 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 optimal policy.The main message of robust results are confirmed by figures 12 to 16. The results from varying the price adjustment probabilities displayed in figure 16 indicates that there is still a substantial difference between the case when $\alpha = 1$ and when $\alpha < 1$ between models. 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

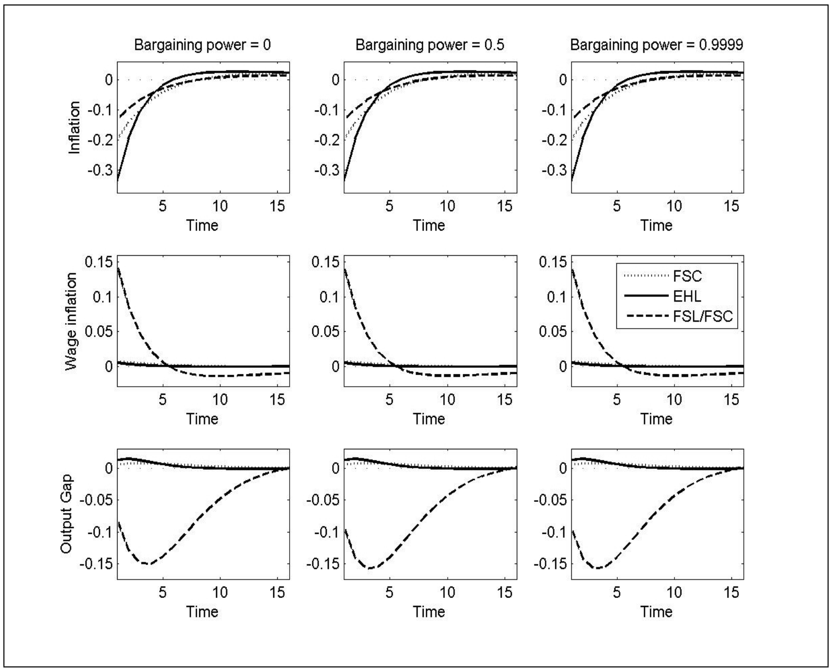

Figure 12: Impulse responses to a one-percent innovation to $\hat{w}_t^*$ under optimal policy for different values of the barganing power.

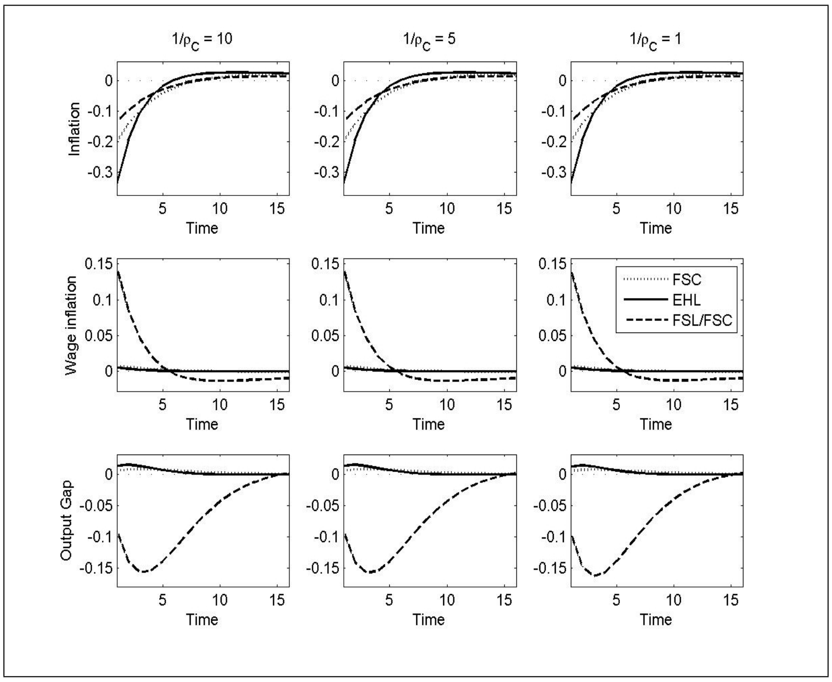

Figure 13: Impulse responses to a one-percent innovation to $\hat{w}_t^*$ under optimal policy for different values of the intertemporal elasticity of substitution in consumption.

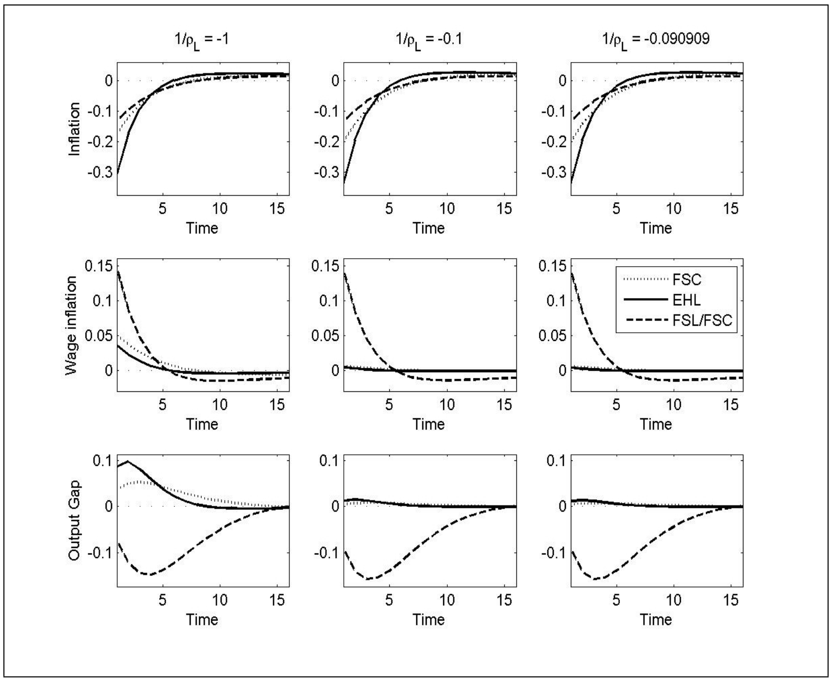

Figure 14: Impulse responses to a one-percent innovation to $\hat{w}_t^*$ under optimal policy for different values of the Frisch labor-supply elasticity.

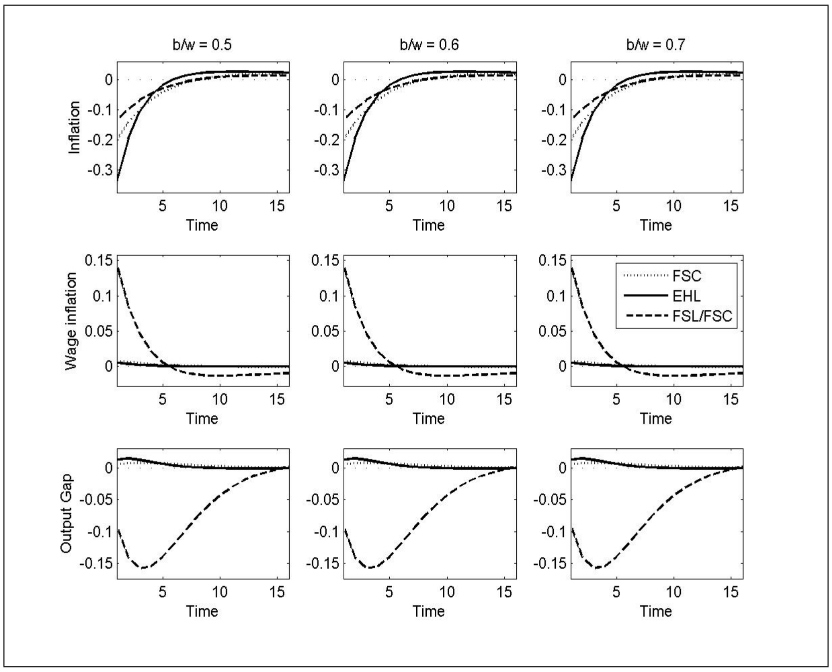

Figure 15: Impulse responses to a one-percent innovation to $\hat{w}_t^*$ under optimal policy for different values of the replacement rate.

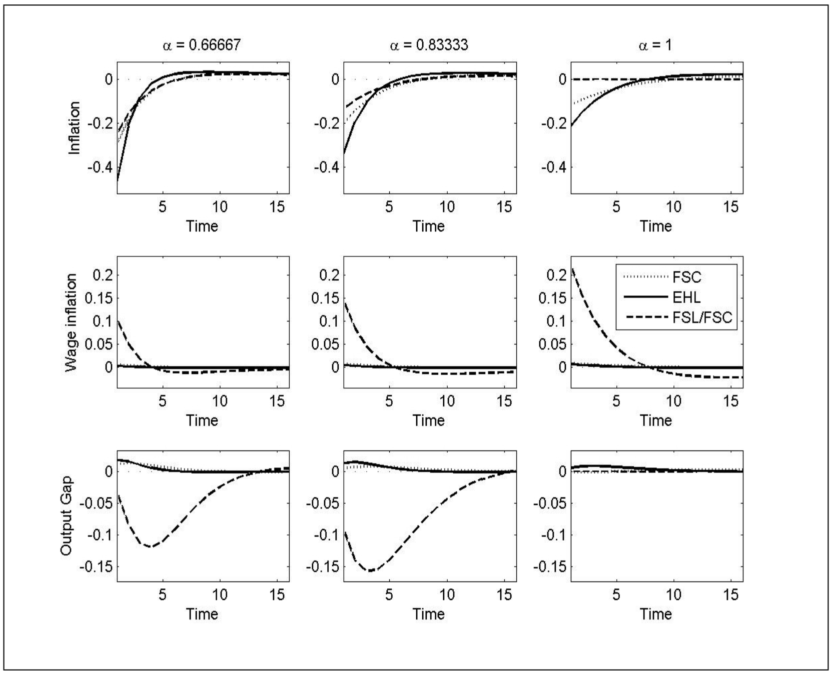

Figure 16: Impulse responses to a one-percent innovation to $\hat{w}_t^*$ under optimal policy for different values of the price adjustment probability α.

in the FSL/FSC model. The reason is that, as can be seen from setting in $\Pi_W = \Pi_1$ in (41) , 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, Henderson, and Levin (2000) formulation, affects the impulse-response functions. As shown in figure 17, this hardly affects the impulse-responses at all.

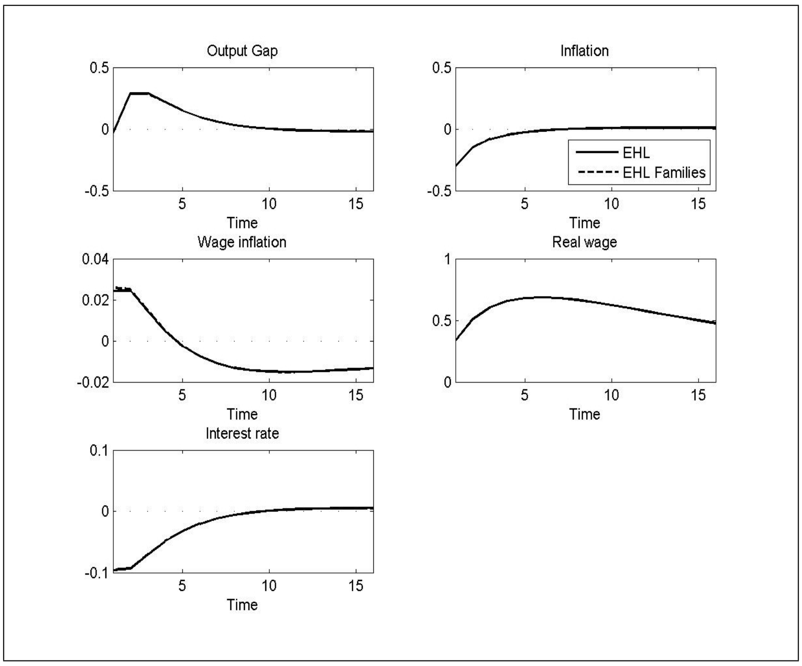

Figure 17: Impulse responses to a one-percent innovation to $\hat{w}_t^*$ when the nominal interest rate is governed by the simple rule in the EHL model with and without relying on a family construct.