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Inflation Dynamics and Labor Adjustments in Japan: A Bayesian DSGE Approach*

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Abstract

Many studies of inflation dynamics assume that in the presence of competitive labor markets firms adjust labor input only at the intensive margin. We consider labor market search and examine the role of the extensive margin for inflation dynamics by estimating three models with distinct labor adjustments. Our Bayesian estimation result shows that the model with only the extensive margin is superior to that with only the intensive one in terms of marginal likelihood. This suggests that the extensive margin may be more important for inflation dynamics in Japan. We also show that introducing the intensive margin into the extensive margin model further improves marginal likelihood. Moreover, we find that real marginal costs in these models with the extensive margin are highly correlated with the Bank of Japan's estimates of the output gap.

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Keywords: Inflation dynamics; Marginal cost; Labor market search; Extensive margin; Bayesian estimation

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1 Introduction

Studies of inflation dynamics have investigated firms' price-setting behavior under monopolistic competition and have considered real marginal cost the main driving force of such dynamics. In determining the marginal cost the labor market plays a crucial role, since labor is one of the most critical factors in production. Many studies assume perfectly competitive labor markets or alternatively propose monopolistically competitive ones in which households set their wages.[1] In the presence of these competitive labor markets, however, firms adjust labor input only at the intensive margin (i.e. labor hours) and hence firms' real marginal cost never reflects their cost involved to adjust employment.

Recently there has been a surge of interest in the role of labor markets for inflation dynamics. The pioneering works by Trigari (2004), Walsh (2005), and Krause and Lubik (2007) introduce labor market search into dynamic stochastic general equilibrium (DSGE) models with price rigidities, along the lines of Mortensen and Pissarides (1994), Merz (1995), and Andolfatto (1996).[2] In these studies the labor adjustment takes place at the extensive margin (i.e. employment), which gives rise to equilibrium unemployment, and wages are determined via bargaining between workers and firms. These characteristics of labor markets are in stark contrast with those of competitive labor markets used in many studies of inflation dynamics. Despite these distinct labor-market specifications, the existing literature on inflation dynamics lacks a formal comparison of them.

In the present paper we fill this gap. Specifically, we use a Bayesian likelihood approach to estimate three models with different labor adjustments and examine the role of the extensive margin for inflation dynamics. The three models we compare differ only in the specification of the labor market, and in each model firms adjust labor input only at the intensive margin, only at the extensive margin, or at both intensive and extensive margins. As in many studies of inflation dynamics, the model with only the intensive margin assumes monopolistically competitive labor markets and households' staggered wage setting. The model with only the extensive margin contains the following labor-market specification. As Trigari (2004) indicates, when

[1] See Christiano et al. (2005), Smets and Wouters (2003, 2007), and Levin et al. (2006), among others.

[2] See also Christoffel and Linzert (2005), Christoffel et al. (2006), Van Zandweghe (2007), Blanchard and Galí (2008), Ravenna and Walsh (2008), Kurozumi and Van Zandweghe (2007), Gertler et al. (2008), Christoffel and Kuester (2008), Krause et al. (2008), and Sveen and Weinke (2008), among others.

firms take Calvo (1983)-style staggered price setting, their employment decisions are highly intractable. To avoid this, employment intermediaries are introduced. Each intermediary employs workers and produces a package of these workers' labor services. Firms use this labor package to produce differentiated goods under monopolistic competition and set prices of these goods on the Calvo-style staggered basis.[3] In addition, it is assumed as in Blanchard and Galí (2008) and Gertler et al. (2008) that there is a hiring cost instead of the fixed cost to post vacancies used in traditional literature on labor market search. This hiring cost increases with the tightness of the labor market. Moreover, it is assumed as in Ravenna and Walsh (2008) and Kurozumi and Van Zandweghe (2007) that a fraction of employed workers leaves their jobs at the beginning of period but has a probability of finding a new job within the period and that new hires become productive instantaneously. The model with both intensive and extensive margins is a modification of the extensive margin model in that labor hours as well as wages are determined via bargaining between employment intermediaries and employed workers.

On the estimation side, we set prior distributions for model parameters, use the Kalman filter to evaluate the likelihood function of each log-linearized model, and apply the Metropolis-Hastings algorithm to draw from posterior distributions of the parameters. We then adopt marginal likelihood to compare the three models. An advantage of this approach is that it penalizes overparametrization. Therefore, a model with more variables does not necessarily rank better unless the additional variables significantly help in explaining data.

The main findings of this paper are as follows. First of all, the model with only the extensive margin is superior to that with only the intensive one in terms of marginal likelihood. This suggests that the extensive margin may be more important for inflation dynamics in Japan. Second, introducing the intensive margin into the extensive margin model further improves marginal likelihood. Last, real marginal costs in these models with the extensive margin are highly correlated with the Bank of Japan's estimates of the output gap.[4] This suggests that such an output gap may be a good proxy of the driving force of inflation dynamics in Japan.

Why does the model with only the extensive margin fit data better than that with only the intensive one? In these models the non-labor market part is identical and thus the crucial

[3]In Krause and Lubik (2007), firms make both employment and price-setting decisions in the presence of a quadratic price adjustment cost.

[4]See Hara et al. (2006) for this series of the output gap.

difference is the channel from real wages to inflation via real marginal cost. In the model with only the intensive margin, firms' marginal cost is identical with unit labor cost under assumed full employment. Since this marginal cost lags far behind inflation by more than two years in Japan, it is hard to replicate such an autocovariance relationship by that model. By contrast, in the model with only the extensive margin, unit labor cost is influenced by employment fluctuations and real marginal cost consists of this unit labor cost and hiring cost. Then, employment in the model is adjusted so that the real marginal cost becomes more correlated with inflation.[5] Therefore, the model with only the extensive margin can far better match the autocovariance between inflation and real wages via the marginal cost and hence fits data better than the model with only the intensive margin.

Among related literature, Bayesian estimation of DSGE models is conducted by Smets and Wouters (2003) for Euro area and by Levin et al. (2006) and Smets and Wouters (2007) for U.S. Rabanal and Rubio-Ramírez (2005) use marginal likelihood to show that a model with monopolistically competitive labor markets and staggered wage setting matches U.S. data far better than a model with perfectly competitive labor markets. In these previous studies, the labor adjustment takes place only at the intensive margin. By contrast, Christoffel et al. (2006), Gertler et al. (2008), and Krause et al. (2008) estimate DSGE models with the extensive margin for Euro area and for U.S. To our knowledge, the present paper is the first to compare DSGE models with the intensive margin and with the extensive margin in terms of marginal likelihood.

As for related studies on Japan, Iiboshi et al. (2006) and Sugo and Ueda (2008) estimate DSGE models similar to those of Smets and Wouters (2003) and Levin et al. (2006). Muto (2008) stresses that the measurement of real marginal cost plays a crucial role in estimating the New Keynesian Phillips curve and shows that the consideration of labor market frictions greatly improves the goodness of fit of this curve to data. These previous studies, however, consider only the intensive margin. With a RBC model with both intensive and extensive margins, Braun et al. (2006) indicate that the intensive margin plays a more important role in labor input fluctuations in Japan. This result is never inconsistent with our result that the

[5]Our Bayesian estimation does not use the employment data, since the aim of this paper is a comparison of the three models with the same data set and the model with only the intensive margin never contains the employment variable. As a support for our procedure, we confirm that the model-implied employment estimated using the Kalman filter captures the actual movements in employment well.

extensive margin may be more important for inflation dynamics in Japan. This is because the labor adjustment at the extensive margin is very costly for firms in Japan and thus fluctuations in hours worked are better able to explain labor input fluctuations. For inflation dynamics, by contrast, real marginal cost is the key factor and therefore the costly labor adjustment at the extensive margin has a crucial influence on such dynamics.

The remainder of the paper proceeds as follows. The next section presents three models with distinct labor adjustments. Section 3 presents our estimation procedure and results. Finally, Section 4 concludes.

2 Three models with distinct labor adjustments

In this section we present three models with distinct labor adjustments. These models differ only in the specification of the labor market, and in each model firms adjust labor input only at the intensive margin, only at the extensive margin, or at both intensive and extensive margins. Thus, we first present the common part of the three models and then turn to the three specifications of the labor market. Note that in the following equations, all variables without time subscript show their steady state values and all hatted variables show log-deviation from these values.

2.1 Common part of the three models

The three models contain the following common part, which can also be seen in recent studies, e.g. Rabanal and Rubio-Ramírez (2005) and Levin et al. (2006). First, in the presence of complete insurance markets, households maximize utility functions of final-goods consumption with internal habit formation. The log-linearized first-order conditions with respect to consumption and bond holdings, together with the final-goods market clearing condition,[6] yield

$$\hat{\lambda}_t = \frac{1}{1-\beta\chi}\left\{-\frac{\sigma_C}{1-\chi}(\hat{Y}_t - \chi\hat{Y}_{t-1}) + \varepsilon_{ut} - \beta\chi\left[-\frac{\sigma_C}{1-\chi}(E_t\hat{Y}_{t+1} - \chi\hat{Y}_t) + E_t\varepsilon_{ut+1}\right]\right\}, \quad (1)$$

$$\hat{\lambda}_t = E_t\hat{\lambda}_{t+1} + \hat{R}_t - E_t\hat{\pi}_{t+1}, \quad (2)$$

[6]The three models assume that the capital stock is fixed at the firm level and there are no government spending and no international part, and thus the final-goods market clearing condition shows that output supply matches consumption demand.

where λ_t is the marginal utility of consumption, Y_t is output, ε_{ut} is a preference shock, R_t is the (gross) nominal interest rate, π_t is the (gross) inflation rate, E_t is the expectations operator conditional on information available in period t, $\beta \in (0,1)$ is the subjective discount factor, $\chi \in [0,1)$ is the degree of internal habit persistence, and $\sigma_C > 0$ measures relative risk aversion.

Second, there are a continuum of monopolistically competitive intermediate-goods firms and perfectly competitive final-goods firms. The intermediate-goods firms use a Cobb-Douglas production technology with labor input and a capital stock fixed at the firm level to produce differentiated goods and set prices of these goods on the Calvo (1983)-style staggered basis with indexation to recent past inflation and steady state inflation. The final-goods firms use a CES production technology to combine the intermediate goods into final goods and sell them to households. Consequently, the inflation rate is determined by

$$\hat{\pi}_t = \frac{\gamma_p}{1+\beta\gamma_p}\hat{\pi}_{t-1} + \frac{\beta}{1+\beta\gamma_p}E_t\hat{\pi}_{t+1} + \frac{(1-\xi_p)(1-\beta\xi_p)}{\xi_p(1+\beta\gamma_p)[1+\theta_p(1-\alpha)/\alpha]}(\hat{mc}_t + \varepsilon_{pt}), \tag{3}$$

where mc_t is an 'average' of real marginal cost (Galí et al., 2001), ε_{pt} is a price markup shock, $\xi_p \in (0,1)$ is firms' probability of not reoptimizing prices, $\gamma_p \in [0,1]$ is the degree of price indexation to recent past inflation, $\theta_p > 1$ is the steady state price elasticity of demand for intermediate goods, and $\alpha \in (0,1]$ is the cost share of labor input in the Cobb-Douglas production technology.

Third, a central bank conducts monetary policy by adjusting the nominal interest rate. We assume a Taylor (1993)-style feedback policy rule for the interest rate

$$\hat{R}_t = \phi_R \hat{R}_{t-1} + (1-\phi_R)(\phi_\pi \hat{\pi}_t + \phi_Y \hat{Y}_t) + \varepsilon_{Rt}, \tag{4}$$

where ε_{Rt} is a monetary policy shock, $\phi_R \in [0,1)$ is the degree of interest rate smoothing, and $\phi_\pi, \phi_Y \geq 0$ are the degrees of policy responses to inflation and output.

Forth, as in recent studies on monetary policy, we assume that fiscal policy is Ricardian. That is, fiscal policy appropriately accommodates consequences of monetary policy for the government budget constraint. We thus leave the fiscal side of government hidden.

Last, we assume that the monetary policy shock is i.i.d. and other shocks follow stationary first-order autoregression processes.

2.2 The model with only intensive margin

We now present three distinct specifications of the labor market. The first one is the labor adjustment only at the intensive margin. For this adjustment, many studies of inflation dynamics assume monopolistically competitive labor markets and households' staggered wage setting. In this specification, log-linearized equilibrium conditions are given by (1)−(4) and

$$\hat{Y}_t = \alpha \hat{h}_t + \varepsilon_{at}, \tag{5}$$

$$\hat{mc}_t = \hat{w}_t - \hat{Y}_t, \tag{6}$$

$$\hat{w}_t = \hat{z}_t + \hat{h}_t, \tag{7}$$

$$\hat{\pi}_t^w = \beta E_t \hat{\pi}_{t+1}^w + \frac{(1-\xi_w)(1-\beta\xi_w)}{\xi_w(1+\theta_w\sigma_h)}(\sigma_h \hat{h}_t - \hat{\lambda}_t - \hat{z}_t + \varepsilon_{wt}), \tag{8}$$

$$\hat{\pi}_t^w = \hat{z}_t - \hat{z}_{t-1} + \hat{\pi}_t, \tag{9}$$

where h_t is hours worked, ε_{at} is a productivity shock, w_t and z_t are a real wage per worker and that per hour, σ_h is the inverse of the labor supply elasticity, ε_{wt} is a wage markup shock, ξ_w is households' probability of not reoptimizing wages, θ_w is the steady state wage elasticity of demand for differentiated labor, and π_t^w is the (gross) nominal wage inflation rate. Eq. (5) shows the Cobb-Douglas production technology, (6) represents firms' cost minimization with respect to labor input and illustrates that the marginal cost equals unit labor cost (under assumed full employment), (8) describes households' staggered wage setting, and (7) and (9) give the definitions of the real wage and the nominal wage inflation rate.

2.3 The model with only extensive margin

We turn next to the model with only the extensive margin. This model is in stark contrast to that with only the intensive margin presented above in that firms adjust labor input by changing employment and wages are determined via labor bargaining.

In the model there are employment intermediaries, which post vacancies, employ new hires and provide a package of employed workers' labor services for the intermediate-goods firms under perfect competition. The population size is normalized to one. The time line of period t is as follows. At the beginning of period, the representative intermediary employs n_{t-1} workers, but a fraction $\rho \in (0,1)$ of them separates from the intermediary and joins the pool of job searchers, so that the measure of job searchers is given by

$$u_t = 1 - (1-\rho)n_{t-1}. \tag{10}$$

Then, the employment intermediary posts v_t vacancies and as a consequence, m_t job searchers are newly hired according to a constant returns-to-scale matching technology

$$m_t = \xi_m u_t^{\xi} v_t^{1-\xi}, \tag{11}$$

where $\xi_m > 0$ measures matching productivity and $\xi \in (0,1)$ is the search elasticity of new hire. It is assumed as in Ravenna and Walsh (2008) and Kurozumi and Van Zandweghe (2007) that new hires become productive instantaneously. Thus, the measure of workers providing labor services in period t is given by

$$n_t = (1-\rho)n_{t-1} + m_t. \tag{12}$$

Hiring is costly, depending on the tightness of the labor market. As in traditional literature on labor market search (e.g. Pissarides, 2000), this tightness is measured by the ratio of vacancies to job searchers,

$$x_t \equiv \frac{v_t}{u_t}. \tag{13}$$

Thus, the labor market tightness increases with vacancies v_t but decreases when the measure of job searchers u_t increases. The employment intermediary needs $\gamma x_t m_t$ existing workers to recruit m_t new hires. Therefore, hiring cost is opportunity cost of these workers, who would engage in production if there were no new hire.

We can now set the employment intermediary's profit maximization problem. This intermediary uses a linear technology, which produces $n_t - \gamma x_t m_t$ units of labor packages. Thus, the intermediary maximizes its profit

$$E_t \sum_{j=0}^{\infty} \beta_{t,t+j} [W_{t+j}\left(n_{t+j} - \gamma x_{t+j} m_{t+j}\right) - w_{t+j} n_{t+j}]$$

subject to (10)−(13), where $\beta_{t,t+j} = \beta^j \lambda_{t+j}/\lambda_t$ is the stochastic discount factor and W_t is the real price of labor packages. Thus, the real cost of hiring m_t new workers is $\gamma x_t m_t W_t$. The first-order conditions with respect to n_t and x_t are given by

$$\begin{aligned} W_t &= w_t + J_t - (1-\rho) E_t\, \beta_{t,t+1} \left[\gamma \xi_m W_{t+1} x_{t+1}^{2-\xi} + J_{t+1} \left(1 - \xi_m x_{t+1}^{1-\xi} \right) \right], \\ J_t &= \gamma_\xi x_t W_t, \end{aligned} \tag{14}$$

where $\gamma_\xi = \gamma(2-\xi)/(1-\xi)$ and J_t is the Lagrange multiplier on the law of motion for employment (12) and hence this multiplier represents the marginal value of employment in terms of final goods. Combining these yields

$$W_t = w_t + \gamma_\xi x_t W_t - (1-\rho) E_t\, \beta_{t,t+1} \gamma_\xi x_{t+1} W_{t+1} \left(1 - \frac{\xi_m}{2-\xi} x_{t+1}^{1-\xi}\right). \tag{15}$$

This shows that the real price of labor packages depends not only on real wages but also on the net cost of employing a new hire in the current period t.

We next consider wage bargaining. Wages are determined by Nash bargaining through which a joint surplus from employment is split between the employment intermediary and employed workers. Then, asset values of employed and unemployed workers, V_t and V_{ut}, are given by

$$\begin{aligned} V_t &= w_t + E_t\, \beta_{t,t+1} \left\{[1-\rho(1-p_{ut+1})]V_{t+1} + \rho(1-p_{ut+1})V_{ut+1}\right\}, \\ V_{ut} &= b + E_t\, \beta_{t,t+1} \left[p_{ut+1} V_{t+1} + (1-p_{ut+1})V_{ut+1}\right], \end{aligned}$$

where $p_{ut} = m_t/u_t$ is the job finding rate. Here, $b = b_w w$ denotes the flow value of unemployment, which is measured in units of final goods and includes unemployment benefits as well as other factors such as labor disutility and home production, and $b_w \in (0,1)$ is the ratio of this unemployment value to steady state real wages. Combining the asset values yields

$$V_t - V_{ut} = w_t - b + (1-\rho) E_t\, \beta_{t,t+1} (1-p_{ut+1})(V_{t+1} - V_{ut+1}), \tag{16}$$

which represents workers' net surplus from employment. Then, wages w_t are chosen so as to maximize

$$(V_t - V_{ut})^{\eta_t} (J_t)^{1-\eta_t},$$

where $\eta_t = \eta \exp(\varepsilon_{\eta t})/[1-\eta+\eta\exp(\varepsilon_{\eta t})] \in (0,1)$ measures workers' share of the joint surplus and $\varepsilon_{\eta t}$ is a wage bargaining shock. The first-order condition for the maximization problem leads to

$$V_t - V_{ut} = \frac{\eta_t}{1-\eta_t} J_t, \tag{17}$$

which implies that $V_t - V_{ut} = \eta_t S_t$ and $J_t = (1-\eta_t) S_t$, where $S_t = (V_t - V_{ut}) + J_t$ is the joint surplus, and hence η_t indeed shows workers' share. From (14), (16) and (17), wages are determined as

$$w_t = b + \frac{\eta_t}{1-\eta_t}\gamma_\xi x_t W_t - (1-\rho)E_t\,\beta_{t,t+1}\Big(1-\xi_m x_{t+1}^{1-\xi}\Big)\frac{\eta_{t+1}}{1-\eta_{t+1}}\gamma_\xi x_{t+1}W_{t+1}. \tag{18}$$

Combining this and (15), we have

$$\begin{aligned} w_t &= \eta_t\left\{W_t + (1-\rho)E_t\,\beta_{t,t+1}\gamma_\xi x_{t+1}W_{t+1}\left[1-\frac{\xi_m}{2-\xi}x_{t+1}^{1-\xi} - \Big(1-\xi_m x_{t+1}^{1-\xi}\Big)\frac{\eta_{t+1}(1-\eta_t)}{\eta_t(1-\eta_{t+1})}\right]\right\} \\ &\quad + (1-\eta_t)\,b. \end{aligned}$$

Thus, employed workers are compensated for a fraction η_t of the employment intermediary's earnings and savings on future hiring cost and for the remaining fraction $1-\eta_t$ of the flow value of unemployment.

Finally, the resource constraint for labor packages is given by

$$N_t = n_t - \gamma x_t m_t, \tag{19}$$

where N_t is the intermediate-goods firms' demand for labor packages, which enters their Cobb-Douglas production technology.

From (10)−(13), (15), (18) and (19), log-linearized equilibrium conditions in the model with only the extensive margin are given by (1)−(4) and

$$\hat{Y}_t = \alpha\hat{N}_t + \varepsilon_{at}, \tag{20}$$

$$\hat{mc}_t = \hat{W}_t + \hat{N}_t - \hat{Y}_t, \tag{21}$$

$$\hat{u}_t = -\frac{(1-\rho)[1-(1-n)]}{1-(1-\rho)[1-(1-n)]}\hat{n}_{t-1}, \tag{22}$$

$$\hat{m}_t = \xi\hat{u}_t + (1-\xi)\hat{v}_t, \tag{23}$$

$$\hat{n}_t = (1-\rho)\hat{n}_{t-1} + \rho\hat{m}_t, \tag{24}$$

$$\hat{x}_t = \hat{v}_t - \hat{u}_t, \tag{25}$$

$$\begin{aligned} \hat{W}_t &= \frac{w}{W}\hat{w}_t + \gamma_\xi x\left\{\hat{x}_t + \hat{W}_t - \beta(1-\rho)E_t\left[\left(1-\frac{\xi_m x^{1-\xi}}{2-\xi}\right)\Big(\hat{\lambda}_{t+1} - \hat{\lambda}_t + \hat{W}_{t+1}\Big)\right.\right. \\ &\quad \left.\left. + \Big(1-\xi_m x^{1-\xi}\Big)\hat{x}_{t+1}\right]\right\}, \end{aligned} \tag{26}$$

$$\begin{aligned} \hat{w}_t &= \frac{\eta\gamma_\xi xW}{w(1-\eta)}\Big(\hat{x}_t + \hat{W}_t + \varepsilon_{\eta t} - \beta(1-\rho)E_t\Big\{\Big(1-\xi_m x^{1-\xi}\Big)\Big(\hat{\lambda}_{t+1} - \hat{\lambda}_t + \hat{W}_{t+1} + \varepsilon_{\eta t+1}\Big) \\ &\quad + \Big[1-(2-\xi)\xi_m x^{1-\xi}\Big]\hat{x}_{t+1}\Big\}\Big), \end{aligned} \tag{27}$$

$$\hat{N}_t = \frac{n}{N}\hat{n}_t - \Big(\frac{n}{N}-1\Big)(\hat{m}_t + \hat{x}_t). \tag{28}$$

Combining (21), (26) and (28) leads to

$$\begin{aligned}\hat{mc}_t \;=\; & \hat{w}_t - \hat{Y}_t + \hat{n}_t - \Big(1 - \frac{w}{W}\Big)\hat{w}_t - \Big(1 - \frac{n}{N}\Big)(\hat{n}_t - \hat{m}_t - \hat{x}_t) + \gamma_\xi x \Big\{ \hat{x}_t + \hat{W}_t \\ & - \beta(1-\rho)\Big[\Big(1 - \frac{\xi_m x^{1-\xi}}{2-\xi}\Big)\Big(E_t\hat{\lambda}_{t+1} - \hat{\lambda}_t + E_t\hat{W}_{t+1}\Big) + \Big(1 - \xi_m x^{1-\xi}\Big)E_t\hat{x}_{t+1}\Big]\Big\}. \quad (29)\end{aligned}$$

This shows that the marginal cost here depends not only on unit labor cost, $\hat{w}_t - \hat{Y}_t + \hat{n}_t$, but also on other terms reflecting the hiring cost, which is influenced by the labor market tightness x_t. This marginal cost is in contrast with that of the model with only the intensive margin given in (6), even quantitatively as shown later.

2.4 The model with both intensive and extensive margins

We finally present the model with both intensive and extensive margins. This model is a modification of the model with only the extensive margin described above in the following three respects. First, the employment intermediary now maximizes its profit

$$E_t \sum_{j=0}^{\infty} \beta_{t,t+j} [W_{t+j} h_{t+j} \left(n_{t+j} - \gamma x_{t+j} m_{t+j}\right) - z_{t+j} h_{t+j} n_{t+j}]$$

subject to (10)$-$(13). The first-order conditions with respect to n_t and x_t are given by

$$\begin{aligned} W_t &= z_t + \frac{J_t}{h_t} - (1-\rho) E_t\, \beta_{t,t+1} \left[\gamma \xi_m W_{t+1} \frac{h_{t+1}}{h_t} x_{t+1}^{2-\xi} + \frac{J_{t+1}}{h_t} \left(1 - \xi_m x_{t+1}^{1-\xi}\right) \right], \\ J_t &= \gamma_\xi x_t W_t h_t. \end{aligned} \quad (30)$$

Combining these yields

$$W_t = z_t + \gamma_\xi x_t W_t - (1-\rho) E_t\, \beta_{t,t+1} \gamma_\xi x_{t+1} W_{t+1} \frac{h_{t+1}}{h_t} \left(1 - \frac{\xi_m}{2-\xi} x_{t+1}^{1-\xi}\right). \quad (31)$$

Second, not only wages but also labor hours are determined via bargaining between the employment intermediary and employed workers. The labor disutility now appears in the asset value of employed workers given by

$$V_t \;=\; z_t h_t - \frac{\chi_h h_t^{1+\sigma_h}}{\lambda_t(1+\sigma_h)} + E_t\, \beta_{t,t+1} \left\{ [1 - \rho(1 - p_{ut+1})] V_{t+1} + \rho(1 - p_{ut+1}) V_{ut+1} \right\},$$

where $\chi_h \geq 0$ is a scale parameter for labor disutility relative to consumption utility.[7] Therefore, the difference between the asset values of employed and unemployed workers is

$$V_t - V_{ut} = z_t h_t - \frac{\chi_h h_t^{1+\sigma_h}}{\lambda_t(1+\sigma_h)} - b + (1-\rho) E_t\, \beta_{t,t+1} (1 - p_{ut+1})(V_{t+1} - V_{ut+1}). \quad (32)$$

[7] In the model with only the intensive margin, the scale parameter for labor disutility χ_h disappears in log-linearizing the model.

Then, the first-order conditions for the maximization of $(V_t - V_{ut})^{\eta_t}(J_t)^{1-\eta_t}$ lead to (17) and

$$\frac{\chi_h h_t^{\sigma_h}}{\lambda_t} = W_t. \tag{33}$$

From (17), (30) and (32), wages are determined as

$$\begin{aligned} w_t \;=\; z_t h_t \;&=\; b + \frac{\chi_h h_t^{1+\sigma_h}}{\lambda_t(1+\sigma_h)} + \frac{\eta_t}{1-\eta_t}\gamma_\xi x_t W_t h_t \\ &\quad - (1-\rho)E_t\,\beta_{t,t+1}\left(1-\xi_m x_{t+1}^{1-\xi}\right)\frac{\eta_{t+1}}{1-\eta_{t+1}}\gamma_\xi x_{t+1}W_{t+1}h_{t+1}. \end{aligned} \tag{34}$$

Last, the resource constraint for labor packages is now given by

$$N_t = h_t(n_t - \gamma x_t m_t). \tag{35}$$

Therefore, log-linearized equilibrium conditions in the model with both intensive and extensive margins are given by (1)−(4), (20)−(25), and

$$\begin{aligned} \hat{W}_t &= \frac{z}{W}\hat{z}_t + \gamma_\xi x\Big\{\hat{x}_t + \hat{W}_t - \beta(1-\rho)E_t\Big[\Big(1-\frac{\xi_m x^{1-\xi}}{2-\xi}\Big)(\hat{\lambda}_{t+1} - \hat{\lambda}_t + \hat{W}_{t+1} + \hat{h}_{t+1} - \hat{h}_t) \\ &\quad + (1-\xi_m x^{1-\xi})\hat{x}_{t+1}\Big]\Big\}, \end{aligned} \tag{36}$$

$$\hat{W}_t = \sigma_h\hat{h}_t - \hat{\lambda}_t, \tag{37}$$

$$\hat{w}_t = \hat{z}_t + \hat{h}_t, \tag{38}$$

$$\begin{aligned} \hat{w}_t &= \frac{\chi_h h^{1+\sigma_h}}{w\lambda}\Big(\hat{h}_t - \frac{1}{1+\sigma_h}\hat{\lambda}\Big) + \frac{\eta\gamma_\xi x W}{z(1-\eta)}\Big(\hat{x}_t + \hat{W}_t + \hat{h}_t + \varepsilon_{\eta t} - \beta(1-\rho)E_t\Big\{(1-\xi_m x^{1-\xi}) \\ &\quad \times(\hat{\lambda}_{t+1} - \hat{\lambda}_t + \hat{W}_{t+1} + \hat{h}_{t+1} + \varepsilon_{\eta t+1}) + [1-(2-\xi)\xi_m x^{1-\xi}]\hat{x}_{t+1}\Big\}\Big), \end{aligned} \tag{39}$$

$$\hat{N}_t = \hat{h}_t + \frac{hn}{N}\hat{n}_t - \Big(\frac{hn}{N} - 1\Big)(\hat{m}_t + \hat{x}_t). \tag{40}$$

3 Model estimation

In this section, we first illustrate our estimation procedure and then present and discuss our estimation results.

3.1 Estimation procedure

We use four quarterly Japanese time series as observable variables: the CPI inflation rate (CPIXSDOT),[8] real GDP per potential labor force (GDP), the call rate (CALL), and the

[8] Fresh foods are excluded and the effects of changes in the VAT rate are adjusted.

growth rate of real wage per worker (WDOT), where the real wage is the sum of employee income and net mixed income deflated by the CPI.[9] These series are shown in Figure 1. All the variables, except the call rate, are seasonally adjusted. Real GDP per potential labor force and real wage per worker are detrended by potential GDP per potential labor force. These potential variables are elements used by the Bank of Japan to estimate the output gap (See Hara et al., 2006). Like Sugo and Ueda (2008), the sample period is 1981:1Q to 1995:4Q. This is because the effect of a zero lower bound on nominal interest rates seems to emerge thereafter but our model and estimation method do not take this into account. The corresponding measurement equation is

$$\begin{bmatrix} CPIXSDOT_t \\ GDP_t \\ CALL_t \\ WDOT_t \end{bmatrix} = \begin{bmatrix} \pi \\ 0 \\ r+\pi \\ 0 \end{bmatrix} + \begin{bmatrix} 400\hat{\pi}_t \\ 100\hat{y}_t \\ 400\hat{R}_t \\ 100(\hat{w}_t - \hat{w}_{t-1}) \end{bmatrix},$$

where π and r denote the steady state inflation and real interest rates to be estimated.

Prior distributions for model parameters we estimate are shown in Table 1. For the common parameters of the three models (i.e. $\sigma_C, \chi, \xi_p, \gamma_p, \phi_R, \phi_\pi, \phi_Y, \pi, r, \rho_a, \rho_u, \rho_p, \sigma_a, \sigma_u, \sigma_R, \sigma_p$), we set identical prior distributions. These priors and those for the other parameters of the model with only the intensive margin (i.e. $\sigma_h, \xi_w, \rho_w, \sigma_w$) are chosen based on recent studies such as Smets and Wouters (2003, 2007), Levin et al. (2006), Iiboshi et al. (2006), and Sugo and Ueda (2008). For the remaining parameters of the models with the extensive margin (i.e. $\eta, b_w, \rho_\eta, \sigma_\eta, \chi_h, \gamma$), priors are set according to Christoffel et al. (2006), Gertler et al. (2008), and Krause et al. (2008).

We estimate most parameters of each model but some parameters are calculated from the steady state relationships or calibrated in order to avoid identification issues. The discount factor β is determined by the steady state real interest rate r. The cost share of labor input in the Cobb-Douglas production technology is set at $\alpha = 0.63$ and the steady state price

[9]This paper does not use data on hours worked. This is because we consider all workers including the self-employed, but there is no data on hours worked by these workers. Note also that even for employed workers, hours worked may be poorly measured due to the presence of unreported hours worked and there is no consensus on how to adjust the effects of the so-called "jitan" regulation, which decreased statutory workdays per week in Japan in 1990s.

elasticity of demand for intermediate goods is set at $\theta_p = 6$. In the model with only the intensive margin, we choose the steady state wage elasticity of demand for differentiated labor at $\theta_w = 6$. In the models with the extensive margin, we set the steady state unemployment rate, the job separation rate, and the quarterly capital output ratio at the sample period averages: $1 - n = 0.025$, $\rho = 0.049$, and $k_y = 1.24 \times 4 = 4.96$.[10] We also use Ishizaki and Kato (2003)'s estimates of the matching productivity and the search elasticity of new hire: $\xi_m = 0.8$ and $\xi = 0.47$. The remaining parameters and steady state values are calculated from

$$\begin{aligned}
x &= \left\{\frac{\rho n}{\xi_m[1-(1-\rho)n]}\right\}^{\frac{1}{1-\xi}}, \quad W = \frac{\theta_p - 1}{\theta_p}\alpha k_y^{\frac{1-\alpha}{\alpha}}, \\
\gamma_\xi &= \gamma\frac{2-\xi}{1-\xi} = \frac{1}{x\left\{1-\beta(1-\rho)\left(1-\frac{\xi_m x^{1-\xi}}{2-\xi}\right)+\frac{\eta[1-\beta(1-\rho)(1-\xi_m x^{1-\xi})]}{(1-\eta)(1-b_w)}\right\}}, \\
N &= n - \gamma x^{2-\xi}\xi_m[1-(1-\rho)n], \qquad w = \frac{\gamma_\xi x W \eta\left[1-\beta(1-\rho)\left(1-\xi_m x^{1-\xi}\right)\right]}{(1-\eta)(1-b_w)}
\end{aligned}$$

in the model with only the extensive margin and from

$$\begin{aligned}
x &= \left\{\frac{\rho n}{\xi_m[1-(1-\rho)n]}\right\}^{\frac{1}{1-\xi}}, \qquad W = \frac{\theta_p - 1}{\theta_p}\alpha k_y^{\frac{1-\alpha}{\alpha}}, \\
N &= \left(\frac{(1-\chi)(1-\beta\chi)\{n-\gamma x^{2-\xi}\xi_m[1-(1-\rho)n]\}^{\sigma_h}}{\chi_h} W k_y^{-\frac{\sigma_C(1-\alpha)}{\alpha}}\right)^{\frac{1}{\sigma_h+\sigma_C}}, \\
w &= \frac{N}{(1-b_w)\{n-\gamma x^{2-\xi}\xi_m[1-(1-\rho)n]\}}\left(\frac{\eta\gamma x W(2-\xi)}{(1-\eta)(1-\xi)}[1-\beta(1-\rho)(1-\xi_m x^{1-\xi})]\right. \\
&\quad \left. + \frac{\chi_h N^{\sigma_h+\sigma_C}}{(1-\chi)(1-\beta\chi)(1+\sigma_h)\{n-\gamma x^{2-\xi}\xi_m[1-(1-\rho)n]\}^{\sigma_h}} k_y^{\frac{\sigma_C(1-\alpha)}{\alpha}}\right), \\
\lambda &= (1-\chi)(1-\beta\chi)\left(N k_y^{\frac{1-\alpha}{\alpha}}\right)^{-\sigma_C}, \quad h = \frac{N}{n-\gamma x^{2-\xi}\xi_m[1-(1-\rho)n]}, \quad z = \frac{w}{h}
\end{aligned}$$

in the model with both extensive and intensive margins.[11]

Finally, as in recent studies taking the Bayesian likelihood approach to estimate DSGE models, we use the Kalman filter to evaluate the likelihood function of each log-linearized model and apply the Metropolis-Hastings algorithm to draw from posterior distributions of the model parameters.

[10] We use the unemployment rate data from the *Labor Force Survey*, the job separation rate data (industries covered, establishments with 30 employees or more) from the *Monthly Labour Survey*, and the capital stock data from the *Japan Industrial Productivity (JIP) Database*. The unemployment and job separation rates are quarterly and seasonally adjusted.

[11] In this model the scale parameter for hiring cost, γ, is estimated.

3.2 Estimation results

We now present our estimation results. To discuss them, we compare our estimates with Iiboshi et al. (2006) (henceforth INW) and Sugo and Ueda (2008) (henceforth SU), who use Japanese data to estimate DSGE models similar to Smets and Wouters (2003) and Levin et al. (2006).

Figures 2−4 show prior and posterior distributions of parameters of the three models and Table 2 reports the posterior mean of each model parameter and its 90% HPD (Highest Posterior Density) interval.[12] We can see that the common structural parameters are stable across the three models. Our estimates of relative risk aversion σ_C are around 1.75 and lie between the two Japanese estimates of 1.25 (SU) and 2.04 (INW). The probability of not reoptimizing prices ξ_p, whose estimates are around 0.75, is also between 0.65 (INW) and 0.88 (SU). While our estimates of habit persistence χ are around 0.88 and are larger than theirs (0.64, INW; 0.10, SU), those of price indexation to recent past inflation γ_p of around 0.18 are smaller than theirs (0.61, INW; 0.86, SU). Our specification of monetary policy is almost the same as INW, who obtain similar estimates of $\phi_R = 0.68$, $\phi_\pi = 1.59$, and $\phi_Y = 0.05$. The steady state values of inflation and real interest rates are estimated as around 1.75% and 2.45%. The common shock parameters are also stable across the three models.

Our estimates of labor market parameters have following features. The inverse of the labor supply elasticity σ_h is around 2, which is comparable to 2.43 (INW) and 2.15 (SU). The probability of not reoptimizing wages $\xi_w = 0.54$ is slightly higher than 0.37 (INW) and 0.52 (SU). In the model with only the extensive margin, our estimates of the steady state worker share in wage bargaining $\eta = 0.56$ and the ratio of the flow value of unemployment to wages $b_w = 0.99$ are almost the same as those Gertler et al. (2008) estimate with U.S. data in the case of period-by-period wage bargaining, 0.58 and 0.98. Hagedorn and Manovskii (2008) argue that the unemployment flow value needs to be close to wages in order for the labor market search framework to replicate actual movements in U.S. real wages. Yet, in our model with both extensive and intensive margins, the ratio of the flow value of unemployment to wages, $b_w = 0.82$, becomes smaller by introducing labor disutility explicitly.

We turn next to the comparison of the three models in the goodness of fit to the data. Marginal likelihood of each model is reported in Table 3. We can see that the model with only

[12]We use Brooks and Gelman (1998)'s measure to check the convergence of parameters.

the extensive margin is superior to that with only the intensive one in terms of marginal likelihood. This suggests that the extensive margin may be more important for inflation dynamics in Japan. We also see that introducing the intensive margin into the extensive margin model further improves marginal likelihood.

3.3 Why do the models with the extensive margin fit the data better?

In this subsection, we address the question of why the model with only the extensive margin fits the data better than that with only the intensive one. To this end, we compute autocovariance between output, real wages, inflation and the nominal interest rate in the data and its 90% posterior interval in each model. These are shown in Figures 5−7. Regarding the high performance of the models with the extensive margin in terms of marginal likelihood, we can see that these models match the autocovariance between real wages and the other three better than that with only the intensive one. As can be seen in Figure 8, the former models can match the autocovariance between inflation and real wages better. Recall that the non-labor market part is identical among the three models. This suggests that the crucial difference among the three models is the channel from real wages to inflation via real marginal cost. In the model with only the intensive margin, marginal cost equals unit labor cost under assumed full employment, as shown in (6). Figure 9 presents autocovariance between inflation and real marginal cost. In this figure, we can see that real marginal cost in the model with only the intensive margin lags inflation by more than two years. Such an autocovariance relationship is, however, hard to match with the New Keynesian Phillips curve (3). In the models with the extensive margin, by contrast, unit labor cost is influenced by employment fluctuations, and real marginal cost consists of this unit labor cost and hiring cost as shown in (29). Then, employment in the model is adjusted so that the real marginal cost becomes more correlated with inflation. Indeed, as can be seen in Figure 9, real marginal cost becomes much more correlated with inflation than in the model with only the intensive margin. The employment adjustment in the models with the extensive margin captures the actual movements in employment well. The model with only the extensive margin generates a positive correlation of 0.44 between the model-implied employment variable and the employment data and the model with both the margins yields 0.37. This effect of the employment adjustment on real marginal cost makes the models with the extensive margin far better able to match the autocovariance between inflation and real wages and as a consequence, these models give rise to a higher value of marginal likelihood.

Regarding real marginal cost, we also find that in the models with the extensive margin, this cost is highly correlated with the Bank of Japan's estimates of the output gap (the BoJ output gap), as shown in Figure 10. The finding suggests that the BoJ output gap may be a good proxy of the driving force of inflation dynamics in Japan.

Our estimation result is consistent with those of previous studies on the Japanese economy. Muto (2008) stresses that the measurement of real marginal cost plays a crucial role in estimating the New Keynesian Phillips curve and shows that the consideration of labor market frictions greatly improves the goodness of fit of this curve to data. Our Bayesian estimation shows that introducing labor market search frictions greatly improves the marginal likelihood of the DSGE model with price rigidities. Braun et al. (2006) use a RBC model with both intensive and extensive margins and indicate that the intensive margin plays a more important role in labor input fluctuations in Japan. This result is also consistent with our result that the extensive margin may be more important for inflation dynamics in Japan. This is because the labor adjustment at the extensive margin is very costly for firms in Japan and thus fluctuations in hours worked are better able to explain labor input fluctuations. For inflation dynamics, by contrast, real marginal cost is the key factor and therefore the costly labor adjustment at the extensive margin has a crucial influence on such dynamics.[13]

4 Concluding Remarks

We have estimated three models with distinct labor adjustments and have examined the role of the extensive margin for inflation dynamics in Japan. Our Bayesian estimation result has shown the following three main findings. First of all, the model with only the extensive margin is superior to that with only the intensive one in terms of marginal likelihood. This finding thus suggests that the extensive margin may be more important for inflation dynamics in Japan. Second, introducing the intensive margin into the extensive margin model further improves

[13]A similar argument can be applied to the U.S. economy. Braun et al. (2006) indicate that in U.S. the extensive margin plays a more important role in labor input fluctuations, which may imply that the labor adjustment at the extensive margin is less costly and has a minor influence on inflation dynamics. In fact, using the U.S. data provided by Smets and Wouters (2007), we estimate our models and find that the model with only the intensive margin is superior to that with only the extensive one in terms of marginal likelihood.

marginal likelihood. Last, real marginal costs in these models with the extensive margin are highly correlated with the Bank of Japan's estimates of the output gap. This suggests that such an output gap may be a good proxy of the driving force of inflation dynamics in Japan.

This paper follows previous studies such as Rabanal and Rubio-Ramirez (2005) to assume that the capital stock is fixed at the firm level. In future direction, we will extend our analysis to a model with investment spending as in recent literature. Our preliminary result shows that the main findings obtained in the present paper still survive in the extended model.

References

[1] Andolfatto, David (1996). "Business Cycles and Labor-Market Search." *American Economic Review* 86, 112-132.

[2] Blanchard, Olivier, and Jordi Galí (2008). "Labor Markets and Monetary Policy: A New-Keynesian Model with Unemployment." NBER Working Paper 13897.

[3] Braun, R. Anton, Julen Esteban-Pretel, Toshihiro Okada, and Nao Sudou (2006). "A Comparison of the Japanese and U.S. Business Cycles." *Japan and the World Economy* 18, 441-463.

[4] Brooks, Stephen, and Andrew Gelman (1998). "Some Issues in Monitoring Convergence of Iterative Simulations." In *Proceedings of the Statistical Computing Section 1998*, American Statistical Association.

[5] Calvo, Guillermo A. (1983). "Staggered Prices in a Utility-Maximizing Framework." *Journal of Monetary Economy* 12, 383-398.

[6] Christiano, Lawrence J., Martin Eichenbaum, and Charles L. Evans (2005). "Nominal Rigidities and the Dynamic Effects of a Shock to Monetary Policy." *Journal of Political Economy* 113, 1-45.

[7] Christoffel, Kai, and Tobias Linzert (2005). "The Role of Real Wage Rigidity and Labor Market Frictions for Unemployment and Inflation Dynamics." European Central Bank Working Paper 556.

[8] Christoffel, Kai, Keith Kuester, and Tobias Linzert (2006). "Identifying the Role of Labor Markets for Monetary Policy in an Estimated DSGE Model." European Central Bank Working Paper 635.

[9] Christoffel, Kai, and Keith Kuester (2008). "Resuscitating the wage channel in models with unemployment fluctuations." *Journal of Monetary Economics* 55, 865-887.

[10] Galí, Jordi, Mark Gertler, and J. David López-Salido (2001). "European Inflation Dynamics." *European Economic Review* 45, 1237-1270.

[11] Gertler, Mark, Luca Sala, and Antonella Trigari (2008). "An Estimated Monetary DSGE Model with Unemployment and Staggered Nominal Wage Bargaining." *Journal of Money, Credit and Banking*, forthcoming.

[12] Geweke, John (1999). "Using Simulation Methods for Bayesian Econometric Models: Inference, Development and Communication." *Econometric Reviews* 18, 1-126.

[13] Hara, Naoko, Naohisa Hirakata, Yusuke Inomata, Satoshi Ito, Takuji Kawamoto, Takushi Kurozumi, Makoto Minegishi, and Izumi Takagawa (2006). "The New Estimates of Output Gap and Potential Growth Rate." Bank of Japan Review 2006-E-3.

[14] Hagedorn, Marcus, and Iourii Manovskii (2008). "The Cyclical Behavior of Equilibrium Unemployment and Vacancies Revisited." European Central Bank Working Paper 853; *American Economic Review*, forthcoming.

[15] Iiboshi, Hirokuni, Shin-ichi Nishiyama, and Toshiaki Watanabe (2006). "An Estimated Dynamic Stochastic General Equilibrium Model of the Japanese Economy: A Bayesian Analysis." Mimeo.

[16] Ishizaki, Hironori, and Ryo Kato (2003). "Japan-U.S. Comparison of Labor Market Rigidities and Structural Adjustment." (in Japanese) Bank of Japan International Department Working Paper 03-J-7.

[17] Krause, Michael U., J. David Lopez-Salido, and Thomas A. Lubik (2008). "Inflation Dynamics with Search Frictions: A Structural Econometric Analysis." *Journal of Monetary Economics* 55, 892-916.

[18] Krause, Michael U., and Thomas A. Lubik (2007). "The (Ir)relevance of Real Wage Rigidity in the New Keynesian Model with Search Frictions." *Journal of Monetary Economics* 54, 706-727.

[19] Kurozumi, Takushi, and Willem Van Zandweghe (2007). "Labor Market Search and Interest Rate Policy." Working Paper, Carnegie Mellon University.

[20] Levin, Andrew T., Alexei Onatski, John C. Williams, and Noah Williams (2006). "Monetary Policy under Uncertainty in Micro-founded Macroeconometric Models." In *NBER*

Macroeconomics Annual 2005, edited by Mark Gertler and Kenneth Rogoff, Cambridge MA: MIT Press, 229-287.

[21] Merz, Monika (1995). "Search in the Labor Market and the Real Business Cycle." *Journal of Monetary Economics* 36, 269-300.

[22] Mortensen, Dale T., and Christopher A. Pissarides (1994). "Job Creation and Job Destruction in the Theory of Unemployment." *Review of Economic Studies* 61, 397-415.

[23] Muto, Ichiro (2008). "Estimating a New Keynesian Phillips Curve with a Corrected Measure of Real Marginal Cost: Evidence in Japan." *Economic Inquary*, forthcoming.

[24] Pissarides, Christopher A. (2000). *Equilibrium Unemployment Theory*. Cambridge, MA: MIT Press.

[25] Rabanal, Pau, and Juan F. Rubio-Ramírez (2005). "Comparing New Keynesian Models of the Business Cycle: A Bayesian Approach." *Journal of Monetary Economics* 52, 1151-1166.

[26] Ravenna, Federico, and Carl E. Walsh (2008). "Vacancies, Unemployment, and the Phillips Curve." *European Economic Review*, forthcoming.

[27] Smets, Frank, and Rafael Wouters (2003). "An Estimated Dynamic Stochastic General Equilibrium Model of the Euro Area." *Journal of the European Economic Association* 1, 1123-1175.

[28] Smets, Frank, and Rafael Wouters (2007). "Shocks and Frictions in US Business Cycles: A Bayesian DSGE Approach." *American Economic Review* 97, 586-606.

[29] Sugo, Tomohiro, and Kozo Ueda (2008). "Estimating a Dynamic Stochastic General Equilibrium Model for Japan." *Journal of the Japanese and International Economies*, forthcoming.

[30] Sveen, Tommy, and Lutz Weinke (2008). "New Keynesian Perspectives on Labor Market Dynamics." *Journal of Monetary Economics* 55, 921-930.

[31] Trigari, Antonella (2004). “Equilibrium Unemployment, Job Flows and Inflation Dynamics.” European Central Bank Working Paper 304; *Journal of Money, Credit and Banking*, forthcoming.

[32] Van Zandweghe, Willem (2007). “On-The-Job Search, Sticky Prices, and Persistence.” Working Paper, Carnegie Mellon University.

[33] Walsh, Carl E. (2005). “Labor Market Search, Sticky Prices, and Interest Rate Policies.” *Review of Economic Dynamics* 8, 829-849.

Table 1: Prior distributions of model parameters

Parameter		Distribution	Mean	90% interval
Common parameters				
σ_C	relative risk aversion	Gamma	2.00	[0.68, 3.88]
χ	consumption habit persistence	Beta	0.60	[0.25, 0.90]
ξ_p	probability of not reoptimizing prices	Beta	0.50	[0.17, 0.83]
γ_p	price indexation to past inflation	Beta	0.50	[0.17, 0.83]
ϕ_R	interest rate smoothing	Beta	0.75	[0.57, 0.90]
ϕ_π	policy response to inflation	Normal	1.50	[1.17, 1.83]
ϕ_Y	policy response to output	Normal	0.50	[0.17, 0.83]
π	steady state inflation rate	Normal	1.00	[-0.64, 2.64]
r	steady state real interest rate	Normal	2.00	[0.36, 3.64]
ρ_a	productivity shock persistence	Beta	0.50	[0.25, 0.75]
ρ_u	preferences shock persistence	Beta	0.50	[0.25, 0.75]
ρ_p	price markup shock persistence	Beta	0.60	[0.34, 0.83]
$\sigma_a \times 10^2$	s.d. of productivity shock innovation	Inv gamma	0.50	[0.11, 1.41]
$\sigma_u \times 10^2$	s.d. of preferences shock innovation	Inv gamma	5.00	[1.05, 14.1]
$\sigma_R \times 10^2$	s.d. of monetary policy shock	Inv gamma	0.50	[0.11, 1.41]
$\sigma_p \times 10^2$	s.d. of price markup shock innovation	Inv gamma	5.00	[1.05, 14.1]
Labor market parameters				
σ_h	inverse of labor supply elasticity	Gamma	2.00	[0.68, 3.88]
ξ_w	probability of not reoptimizing wages	Beta	0.40	[0.10, 0.75]
ρ_w	wage markup shock persistence	Beta	0.60	[0.34, 0.83]
$\sigma_w \times 10^2$	s.d. of price markup shock innovation	Inv gamma	5.00	[1.05, 14.1]
η	steady state worker share in wage bargaining	Beta	0.50	[0.17, 0.83]
b_w	flow-value-of-unemployment wage ratio	Beta	0.75	[0.50, 1.00]
ρ_η	wage bargaining shock persistence	Beta	0.75	[0.47, 0.95]
$\sigma_\eta \times 10^2$	s.d. of wage bargaining shock	Inv gamma	20.0	[4.22, 56.3]
χ_h	scale parameter for labor disutility	Gamma	0.10	[0.03, 0.19]
γ	scale parameter for hiring cost	Gamma	0.05	[0.02, 0.10]

Table 2: Posterior distributions of model parameters

	Only intensive		Only extensive		Both margins	
	Mean	90% interval	Mean	90% interval	Mean	90% interval
σ_C	1.64	[0.41, 2.73]	1.69	[0.47, 2.83]	1.90	[0.42, 3.36]
χ	0.90	[0.80, 0.98]	0.86	[0.74, 0.96]	0.86	[0.77, 0.96]
ξ_p	0.72	[0.66, 0.79]	0.81	[0.76, 0.86]	0.73	[0.65, 0.80]
γ_p	0.17	[0.03, 0.30]	0.17	[0.03, 0.30]	0.20	[0.03, 0.36]
ϕ_R	0.85	[0.80, 0.90]	0.88	[0.82, 0.93]	0.83	[0.78, 0.89]
ϕ_π	1.49	[1.19, 1.79]	1.48	[1.19, 1.79]	1.49	[1.23, 1.77]
ϕ_Y	0.16	[0.06, 0.25]	0.24	[0.10, 0.39]	0.16	[0.08, 0.24]
π	1.67	[0.84, 2.59]	1.73	[0.86, 2.61]	1.78	[0.97, 2.63]
r	2.49	[1.71, 3.26]	2.28	[1.33, 3.20]	2.61	[1.90, 3.30]
ρ_a	0.41	[0.18, 0.65]	0.44	[0.21, 0.66]	0.37	[0.15, 0.57]
ρ_u	0.60	[0.38, 0.82]	0.62	[0.43, 0.82]	0.57	[0.37, 0.77]
ρ_p	0.77	[0.65, 0.90]	0.67	[0.49, 0.83]	0.68	[0.53, 0.85]
$\sigma_a \times 10^2$	0.52	[0.40, 0.65]	0.53	[0.27, 0.82]	0.54	[0.28, 0.76]
$\sigma_u \times 10^2$	10.9	[3.13, 19.4]	7.90	[2.64, 13.8]	8.58	[2.47, 14.7]
$\sigma_R \times 10^2$	0.14	[0.11, 0.16]	0.13	[0.11, 0.15]	0.14	[0.12, 0.16]
$\sigma_p \times 10^2$	3.10	[1.34, 4.84]	7.98	[2.70, 13.4]	4.25	[1.80, 6.38]
σ_h	1.87	[0.70, 2.89]	–	–	2.55	[1.10, 3.87]
ξ_w	0.54	[0.36, 0.74]	–	–	–	–
ρ_w	0.82	[0.73, 0.93]	–	–	–	–
$\sigma_w \times 10^2$	7.35	[1.90, 13.0]	–	–	–	–
η	–	–	0.56	[0.28, 0.83]	0.50	[0.26, 0.75]
b_w	–	–	0.99	[0.98, 0.99]	0.82	[0.71, 0.94]
ρ_η	–	–	0.94	[0.90, 0.98]	0.96	[0.93, 0.99]
$\sigma_\eta \times 10^2$	–	–	48.7	[28.0, 70.9]	33.3	[17.0, 50.5]
χ_h	–	–	–	–	0.10	[0.02, 0.17]
γ	–	–	–	–	0.04	[0.01, 0.08]

Notes: All estimations are done with Dynare. A sample of 200,000 draws was created and its first 40,000 draws were neglected. The acceptance rate is 0.25.

Table 3: Marginal likelihood of DSGE models.

Model	Marginal likelihood
Only intensive	-287.53
Only extensive	-280.58
Both margins	-277.36

Notes: Marginal likelihood is computed based on Geweke's (1999) Modified Harmonic Mean Estimater.

Figure 1: Data used for estimation

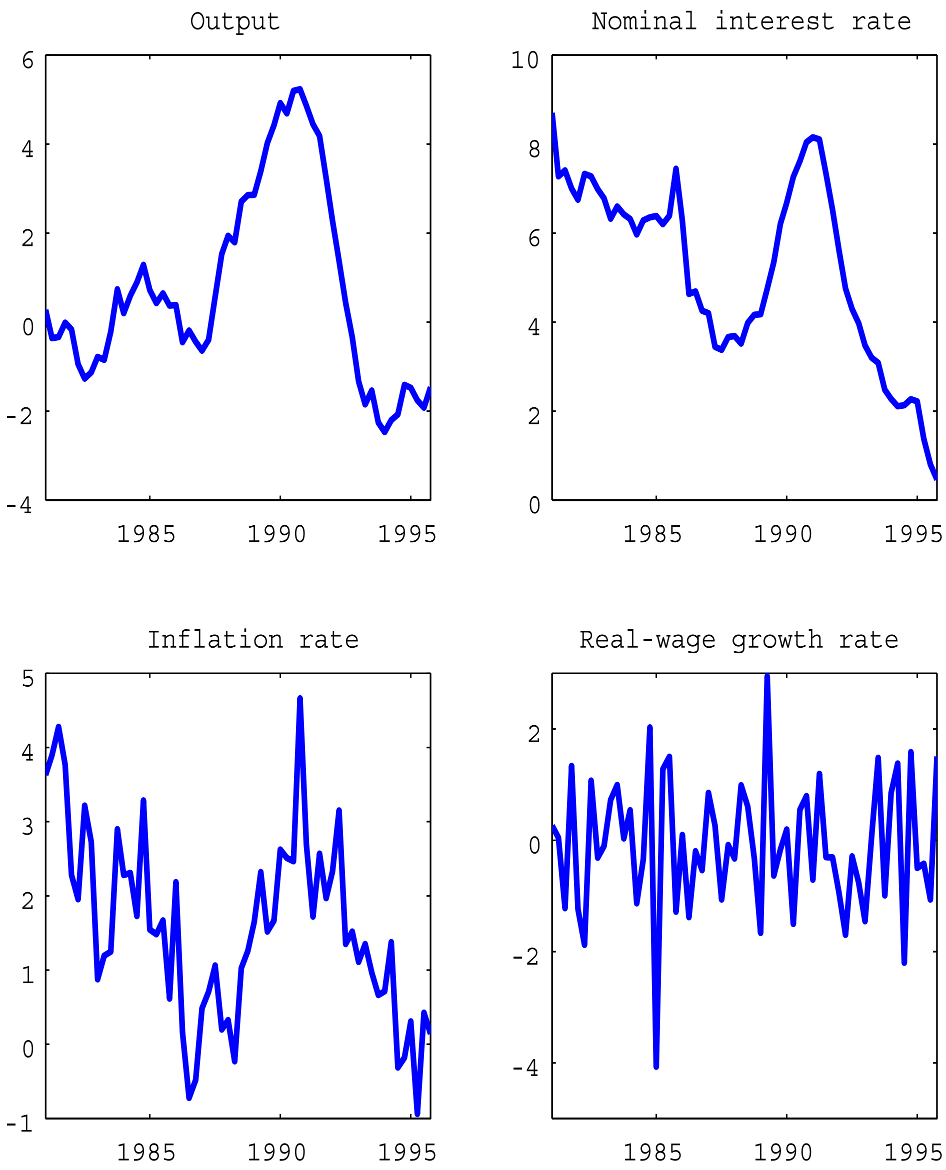


Figure 2: Prior and posterior distributions of model parameters: Only intensive margin

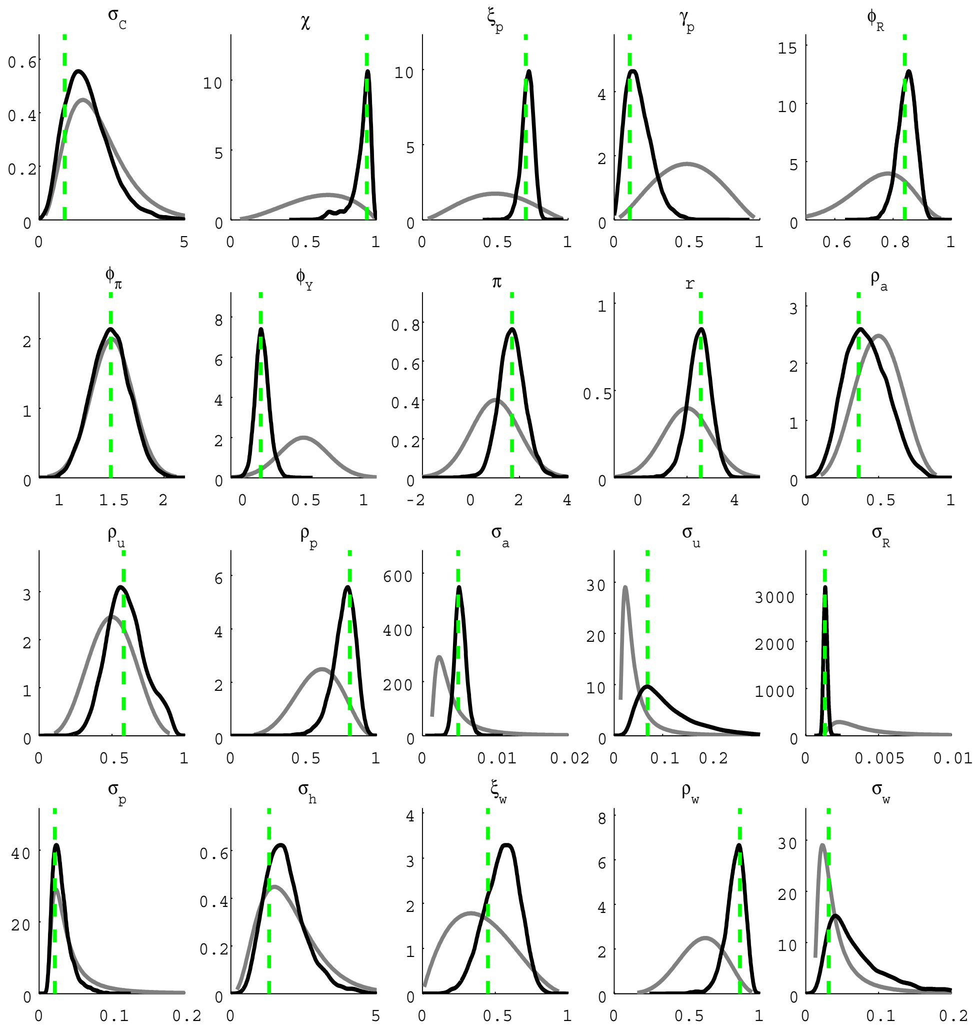


Figure 3: Prior and posterior distributions of model parameters: Only extensive margin

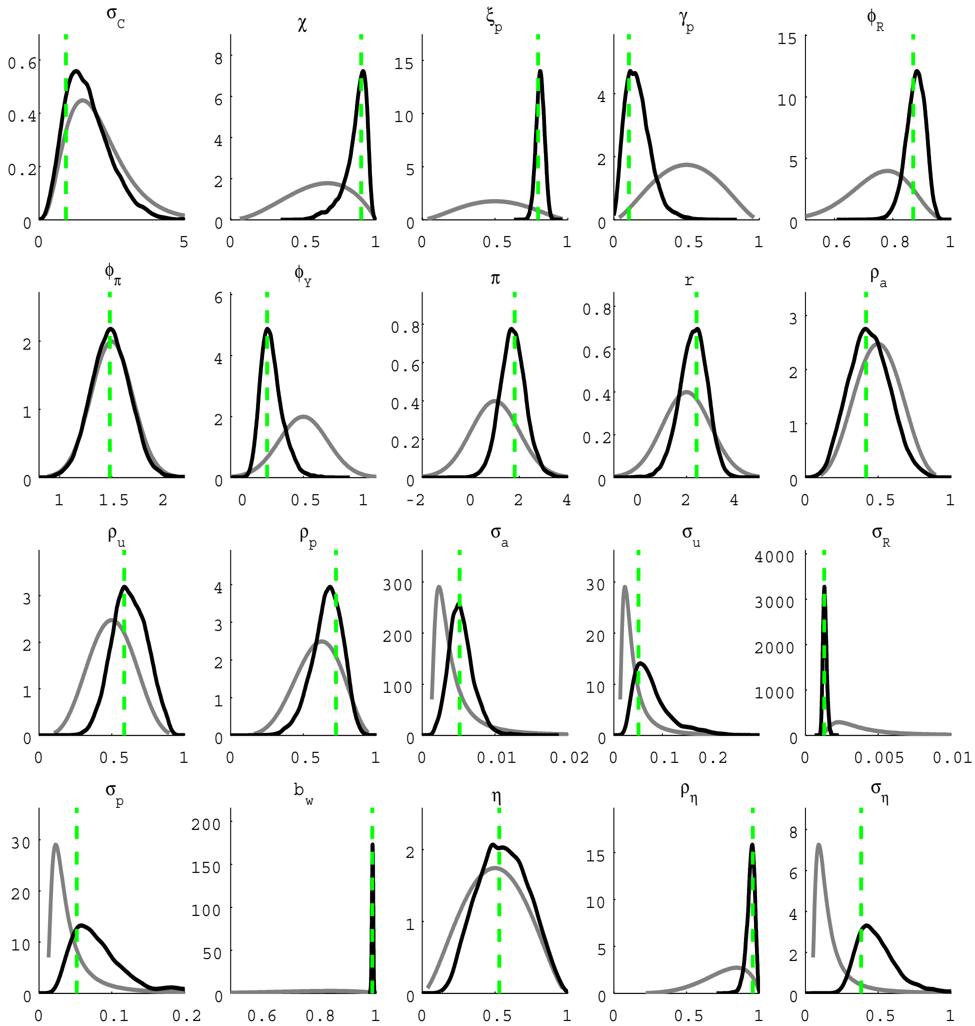


Figure 4: Prior and posterior distributions of model parameters: Both margins

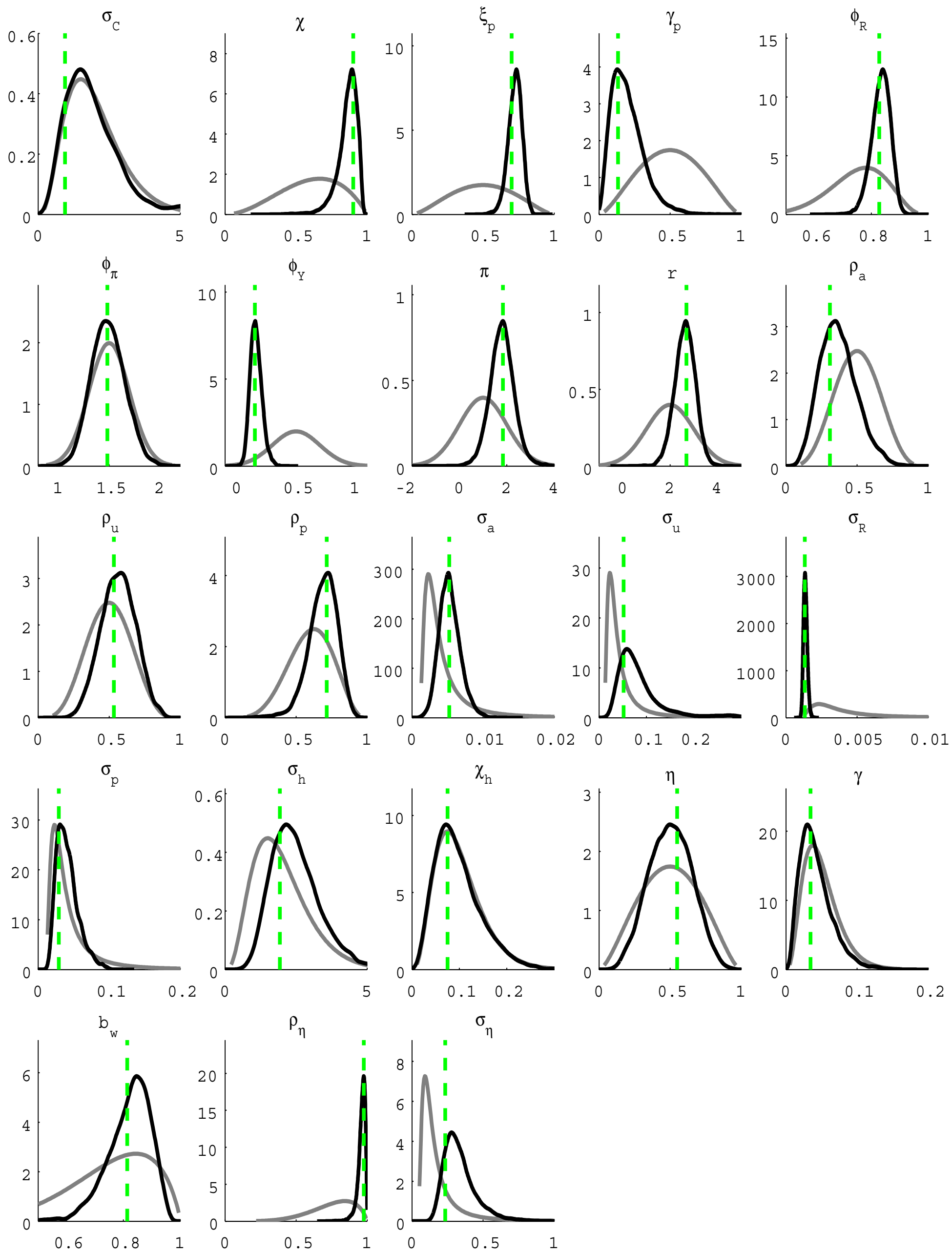


Figure 5: Autocovariance: Only intensive margin

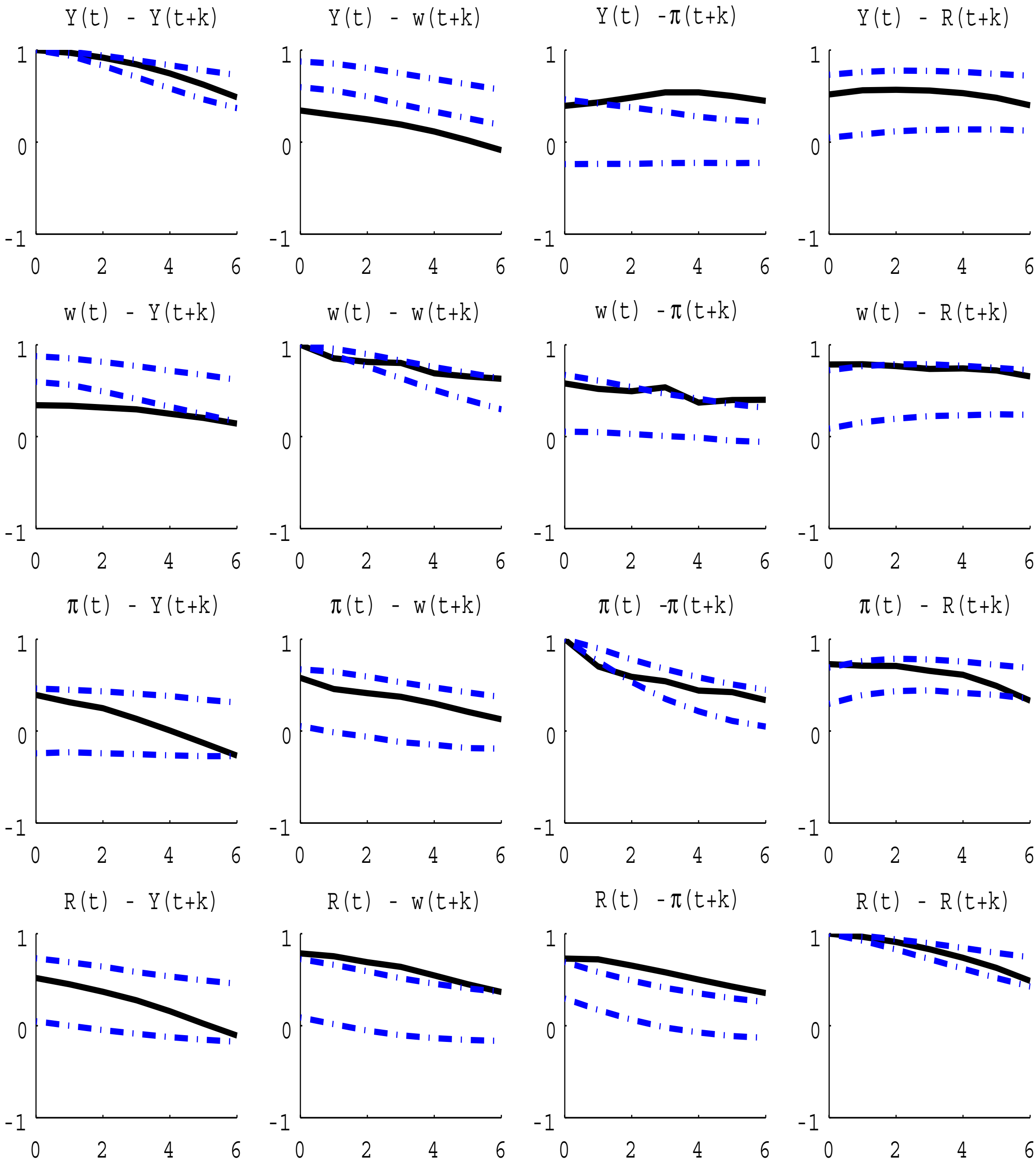


Figure 6: Autocovariance: Only extensive margin

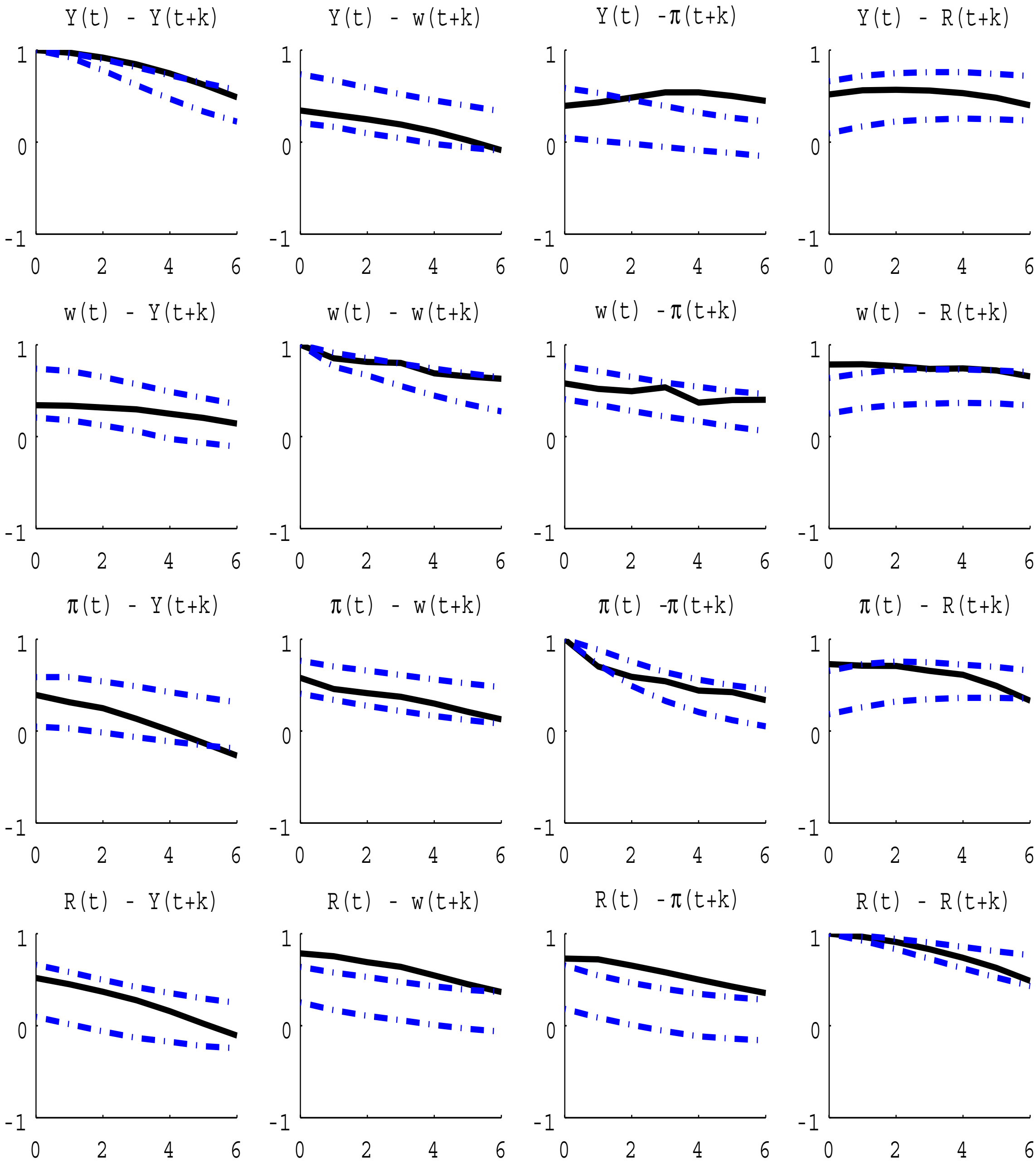


Figure 7: Autocovariance: Both margins

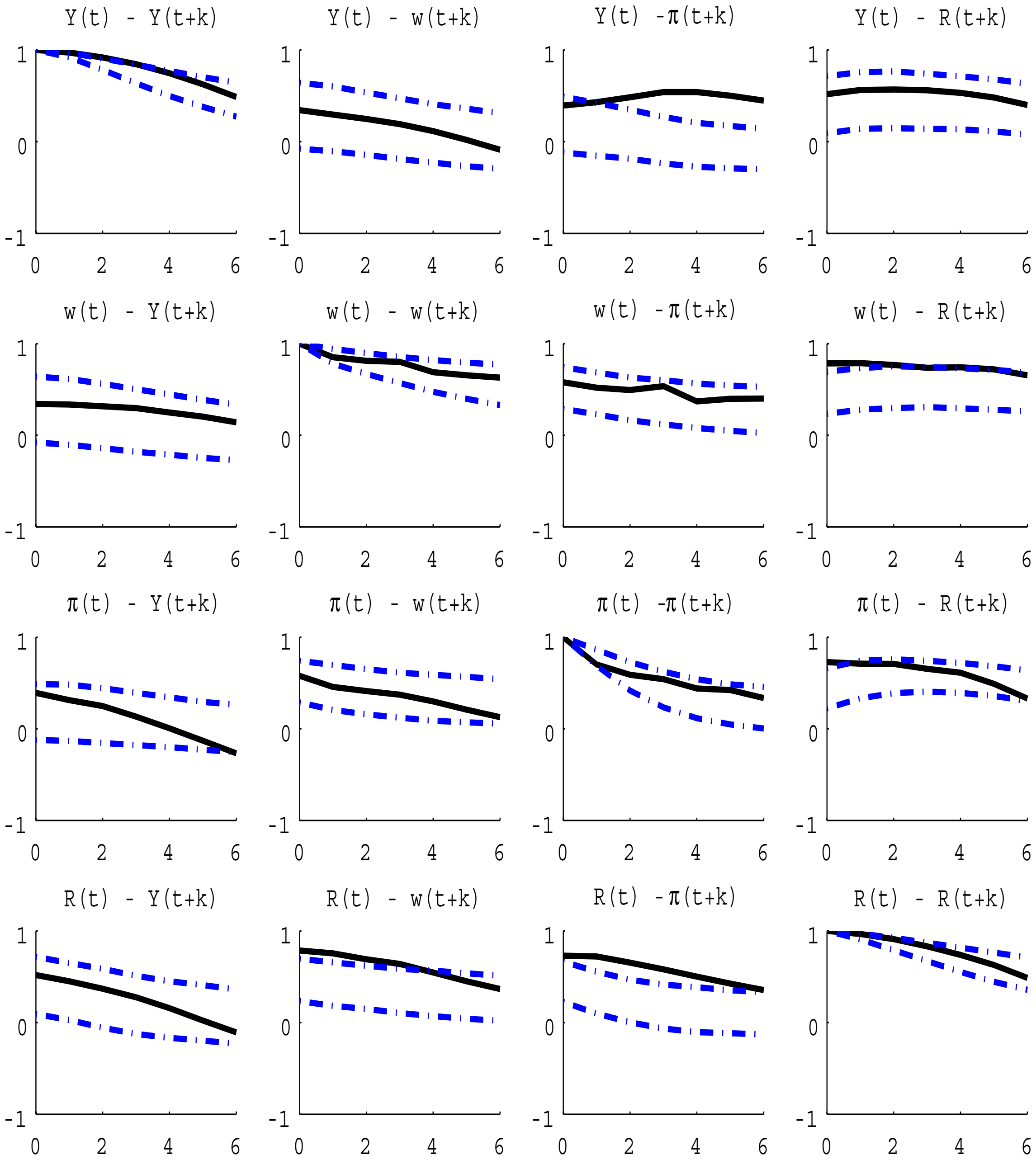
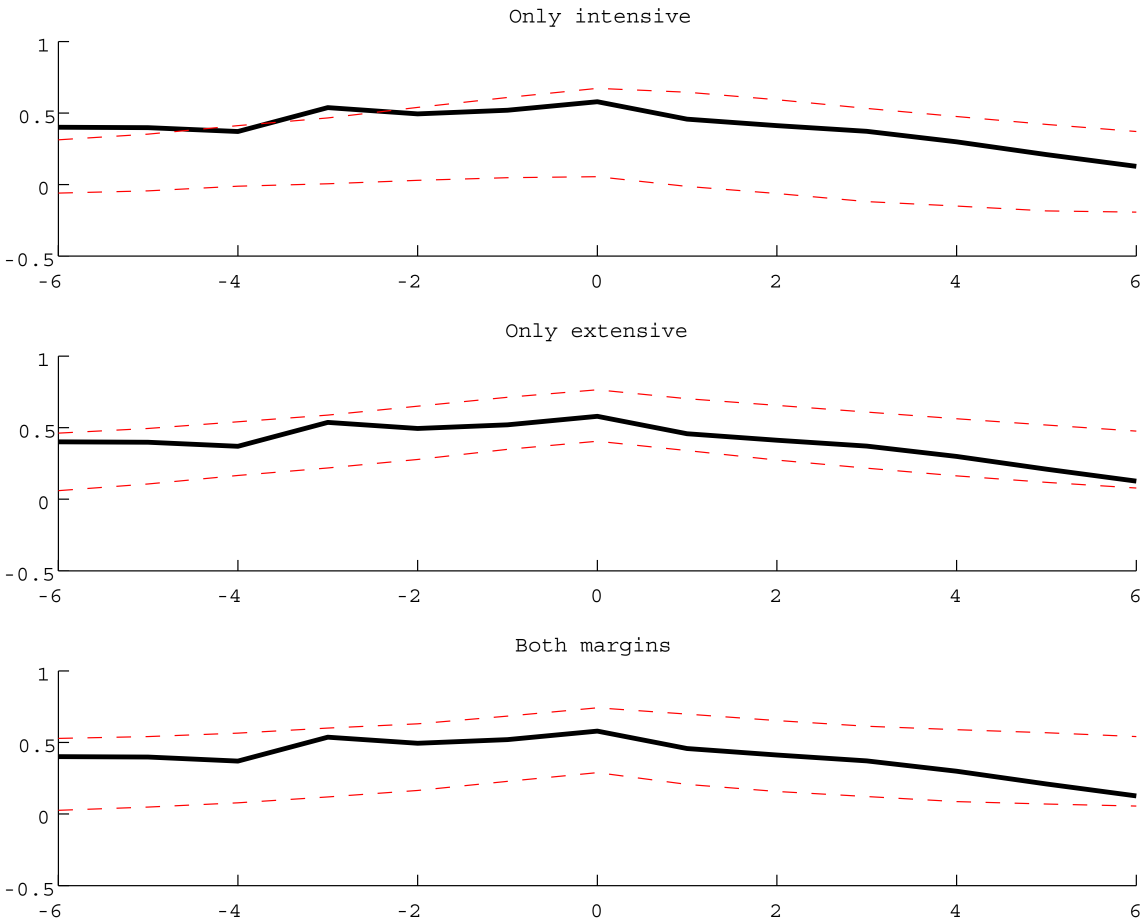
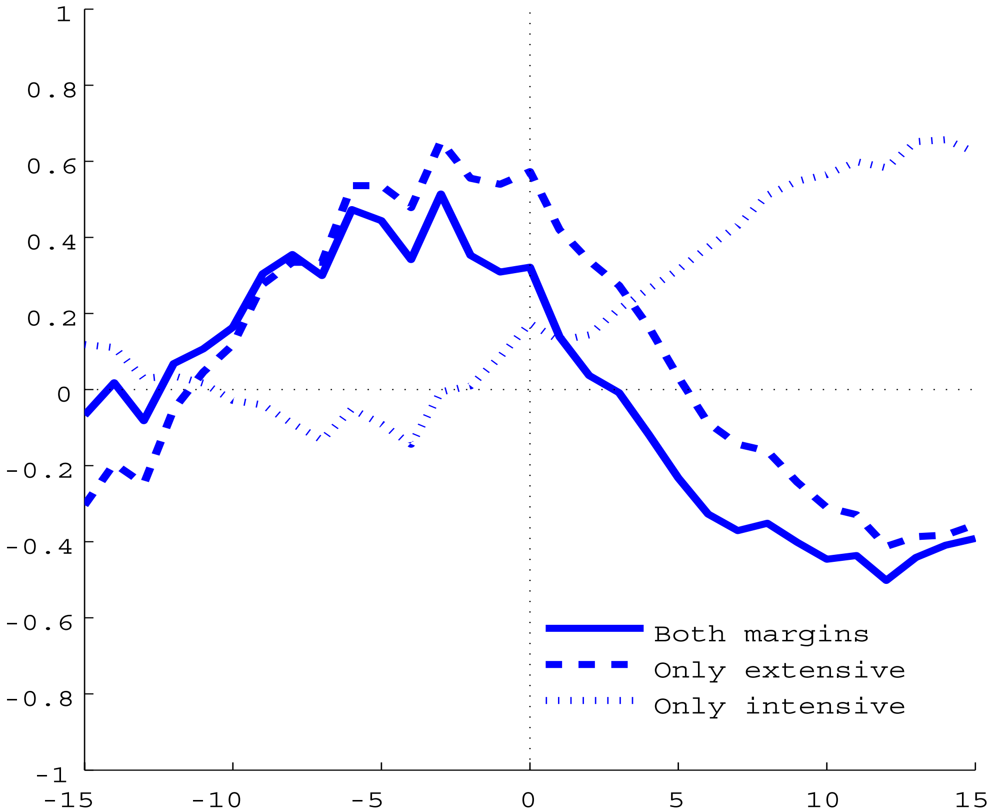


Figure 8: Autocovariance between inflation and real wages: $\pi(t) - w(t+k)$



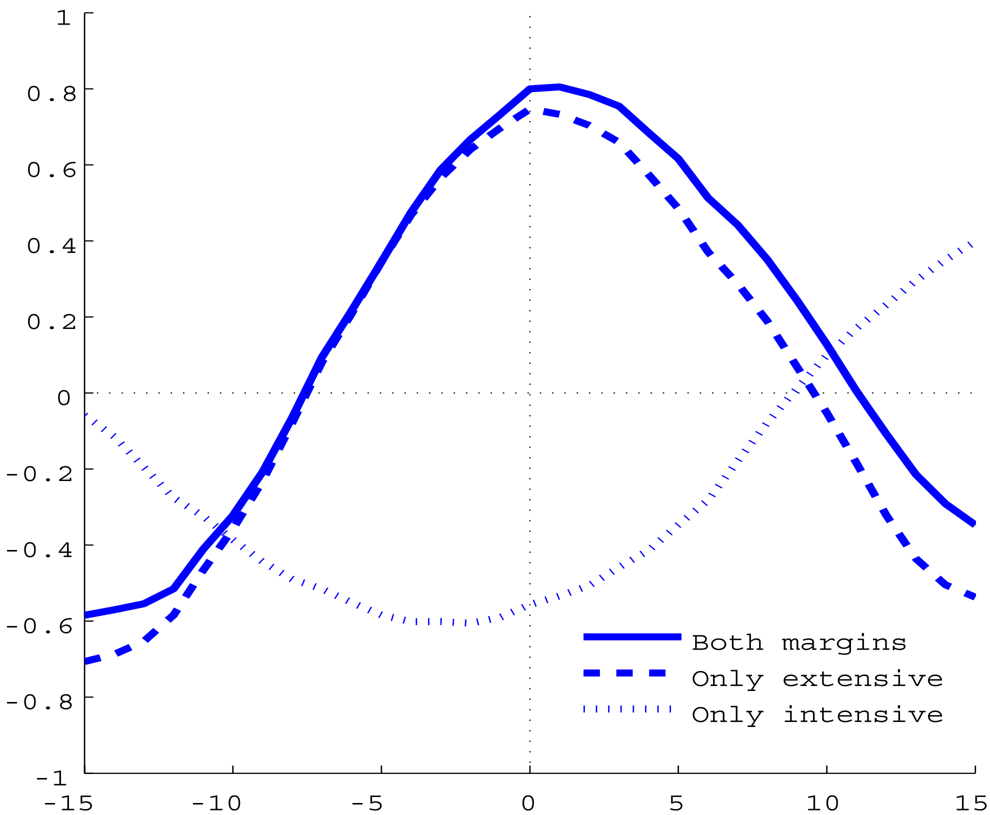
Note: This figure shows the correlation between inflation in period t and real wages in period $t+k$.

Figure 9: Autocovariance between inflation and real marginal cost



Note: This figure shows the correlation between inflation in period t and real marginal cost in period $t+k$.

Figure 10: Autocovariance between real marginal cost and BoJ output gap



Note: This figure shows the correlation between real marginal cost in period t and BoJ output gap in period $t+k$.