Unemployment and Wage Rigidity in Japan: A DSGE Model Perspective

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Abstract

This paper develops a dynamic stochastic general equilibrium model with labor market frictions and nominal wage rigidity. We estimate our model for Japan's economy using Bayesian methods. This allows us to estimate the structural parameters of the Japanese economy, the unobservable shocks and examine their transmission mechanism. We can also study how wage rigidity affects overall model performance. Our analysis demonstrates the importance of including nominal wage rigidity in explaining the Japanese data. We find that while nominal wage rigidity plays only a trivial role in inflation dynamics, it is crucial in determining the response of labor market variables to structural shocks.

JEL classification: E24; E32; J64

Keywords: DSGE models; Bayesian estimation; Labor market search; Wage rigidity

1 Introduction

On one hand, dynamic stochastic general equilibrium (DSGE) models play an important role in macroeconomic analysis. A number of studies documented below develop and estimate DSGE models for Japan's economy. While a typical DSGE model used in these studies assumes a frictionless labor market, a growing literature demonstrates that incorporating labor market frictions improves the empirical performance of DSGE models (Gertler et al. 2008; Krause et al. 2008; Christoffel et al. 2009). Thus, it is worth developing the analysis in a model based on labor market frictions.

On the other hand, a search and matching model that emphasizes labor market fictions has become a standard framework for analyzing an aggregate labor market. A number of studies examine how well a search and matching model accounts for the cyclical properties of Japan's labor market (Amaral and Tasci, 2012; Esteban-Pretel et al., 2011; Miyamoto, 2011; Tawara, 2011).[1] They find that the search and matching model fails to generate observed unemployment fluctuations in response to a technology shock of a reasonable size. They show, in turn, that this volatility puzzle can be solved by incorporating wage rigidity or by modifying parameter values of worker's wage bargaining power and the value of being unemployed. However, these studies use the calibration method and thus it is difficult to pin down key parameter values such as worker's bargaining power and unemployment benefits. Furthermore, it is hard to evaluate the significance of wage rigidity to overall model performance.

In order to tackle these issues, this paper develops and estimates a DSGE model with labor market frictions and wage rigidity for Japan's economy. We incorporate search and matching frictions à la Mortensen and Pissarides (1994) into a standard New Keynesian DSGE model. We also incorporate nominal wage rigidity and wage indexation to past inflation. By doing so, our model provides a more realistic and comprehensive description of the labor market, compared with the traditional frictionless setting toward the labor market. We use Bayesian methods to estimate the model. This allows us to estimate the structural parameters of the Japanese economy, the unobservable shocks and examine their transmission mechanism. We can also study how wage rigidity affects overall model performance.

To best of our knowledge, there are still few papers investigating the Japanese labor market in the context of DSGE model. Our estimation result provides some insights about the distinct features of the Japan economy. Specifically, we find that the Frisch elasticity of labor supply is relatively high. This implies that Japanese firms adjust labor inputs by using the intensive margin more heavily than the extensive margin. The estimate of workers' wage bargaining

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[1]The search and matching model has been criticized for its inability to account for the cyclical properties of the US labor market (Hall, 2005; Shimer, 2005). This failure of the model has been known as the "Shimer puzzle" or the "unemployment volatility puzzle". Recently, a number of studies analyze whether this volatility puzzle holds for the Japanese economy.

power is almost zero, implying that firms can take virtually the entire surplus. This value is strikingly different from the widely used one in most calibration-based studies. We also find that on average price and nominal wages adjust every 5 quarters and 1 year, respectively. Thus, nominal wages are slightly flexible than prices. Our estimation finds a low degree of indexing of wages to past inflation, which suggests a high degree of real wage flexibility. This result is in contrast to Gertler et al (2008), in which they find a high degree of wage indexation to a past inflation in the U.S.

The estimated model allows us to characterize structural shocks. We examine how the model variables react to various structural shocks. We find that demand shocks such as preference, investment, and government policy shocks are important in explaining output variations. Inflation is mainly driven by technology and monetary policy shocks. Unemployment and vacancy fluctuations are explained by matching efficiency and make-up shocks.

We find that the model with nominal wage rigidity matches the data more closely than the model with flexible wages does. This suggests nominal wage rigidity is important to capture Japan's economy. Interestingly, we find that nominal wage rigidity is irrelevant to inflation dynamics, but it affects the response of nominal and real wages considerably when a certain shock hits the economy. For example, a positive technology shock increases real wages in both models with and without wage rigidity, but the increase in real wages is more persistent in the model with nominal wage rigidity. The different responses of real wage in turn influence the firms' hiring decision and thus unemployment rate of economy. Specifically, the persistent response of real wages in the model with wage rigidity implies a smaller response of profits to the technology shock than otherwise. This leads to a smaller response of vacancies and unemployment relative to the flexible wage case. This result is different from Gertler et al. (2008), which demonstrate that the response of labor market variables to the technology shock is greater in the model with wage rigidity than without for the U.S. This difference is due to the low degree of wage indexation in Japan.

We also examine how changing data of wage affects the estimation results. In Japan, payments to a typical worker consist of base wages and special cash earnings (bonuses). In the case where we use base wages as an observable, the estimated degree of wage rigidity is greater than the case in which we use total cash earning (i.e., the sum of base wages and bonuses) as an observable. This implies that Japanese firms maintain a high degree of nominal wage flexibility by adjusting bonuses. Furthermore, we examine whether changing the sample period of data affects our estimation result. In the benchmark case, our data cover the period when the Bank of Japan conducted zero-interest rate policy (ZIRP). As a robustness check, we find that changing the sample period to the pre-ZIRP era does not affect estimated parameters too much.

This paper is closely related to Gertler et al. (2008) that develop a DSGE model with labor market frictions and nominal wage rigidity for the U.S. In their model, firms adjust their labor inputs by changing only the extensive margin. In contrast, our model assumes that firms adjust

labor inputs along both extensive and intensive margins. Our extension reflects the empirical observation that the intensive margins accounts for a large portion of working hours variation in Japan (See for example, Kudoh et al. 2015). Besides, in terms of modelling wage rigidity, we follow Thomas (2008), which has introduced a convenient means to capture staggered wage renegotiation. Our model is also similar to Faccini et al. (2013) that estimate a DSGE model with labor market frictions and wage rigidity for the U.K. However, our model is different from Faccini et al. (2013) as we allow for the possibility of wage indexing to past inflation.

Our paper is also related to the literature of estimating DSGE models for Japan's economy. A number of studies develop and estimate variant DSGE models for Japan's economy (Iiboshi et al. 2006; Sugo and Ueda, 2008; Hirose, 2008; Fueki et al. 2010; Hirose and Kurozumi, 2010; Fujiwara et al., 2011; Iiboshi et al., 2015). While they use DSGE models with frictionless labor markets, we develop and estimate a DSGE model with labor market frictions. Thus, our paper can be viewed as a complement to these previous studies. Ichiue et al. (2012) estimate a DSGE model with labor market friction for the Japanese economy. Our work differs from theirs as we allow for the possibility of wage indexation. Furthermore, the point that we focus on the role of wage rigidity is different.

This sutdy is also related to the recent literature on quantitative implications of the search and matching model. A number of papers examine the ability of the search and matching model to account for the cyclical properties of Japan's labor market (Amaral and Tasci, 2014; Esteban-Pretel et al., 2011; Miyamoto, 2011; Tawara, 2011). While they use the calibration methods and concentrate on the model's ability to replicate a few statistics, we rather study the quantitative implication of the entire model by using Bayesian estimation. Lin and Miyamoto (2014) estimate the standard search and matching model for Japan's labor market by using Bayesian methods. Since we integrate a search and matching setup with a New Keynesian DSGE model, our paper put a forward with Lin and Miyamoto (2014).

The remainder of the paper is organized as follows. Section 2 develops a DSGE model with labor market frictions and nominal wage rigidity. In section 3, we estimate our model by using Japan's data. Section 4 examines the effects of various structural shocks on the economy with estimated parameters. We also discuss the role of nominal wage rigidity. Section 5 conducts robustness checks. Section 6 concludes.

2 The model

We develop a New Keynesian DSGE model with labor market frictions and nominal wage rigidity. The model consists of a representative household, firms, and the government. The household consists of a continuum of workers, who are either employed or unemployed. Employed workers supply labor services and earn wages, while unemployed workers search for jobs. There are three types of firms in the economy: intermediate good firms, wholesale firms,

4

and final good firms. In the beginning of the production chain, intermediate good firms produce homogenous intermediate goods by using labor and capital and sell their products to wholesale firms with competitive prices. Wholesale firms transform homogenous intermediate goods into differentiated intermediate goods in monopolistic competitive markets and set prices à la Calvo (1983). In the end of the production chain, the competitive final good firms combine differentiated intermediate goods to produce homogenous final goods, which are eventually consumed by the household and the government to meet their need in consumption and investment. To make the discussion easier, we rename the intermediate goods firm, wholesale firm and final good firms to firms, wholesalers, and retailers, respectively.

2.1 The labor market

The labor market is subject to search frictions. At the beginning of period t, there are u_t job seekers searching for jobs and a continuum of firms with measure unity is posting vacancies. The total number of vacancies is $v_t = \int_0^1 v_{i,t} di$, where $v_{i,t}$ is the number of vacancies provided by firm i in period t. Define $\mathfrak{m}_t$ as the number of successful matchings, which is governed by the matching function:

$$\mathfrak{m}_t = \vartheta_t u_t^{\xi} v_t^{1-\xi},$$

where ϑ_t is the time-varying matching shock and ξ is the elasticity of the matching function with respect to job seekers. The probability that a firm fills its vacancy is given by $q_t = \mathfrak{m}_t / v_t$. Similarly, the probability that a job seeker finds a job is given by $f_t = \mathfrak{m}_t / u_t$. Note that both firms and workers take q_t and f_t as given.

We assume that newly formed matches become immediately productive. In other words, whenever a job seeker finds a job, she starts to provide her labor service. At the end of period t, a fraction s of employed workers is exogenously separated from each firm, and separated workers cannot search until period $t + 1$.

Defining the number of employed worker as $n_t = \int_0^1 n_{i,t} di$ and combing the above timing assumption, we have the evolution of employment as follows:

$$n_t = (1 - s)n_{t-1} + \mathfrak{m}_t.$$

Then, the number of unemployed worker in period t is $U_t = 1 - n_t$. The number of job seekers in the beginning of period t is given by

$$
\begin{aligned}
u_t &= u_{t-1} + s n_{t-1} \\
&= 1 - n_{t-1} + s n_{t-1}.
\end{aligned}
$$

2.2 The household

There is a representative household with a continuum of members of measure unity. A member of the household is either employed or unemployed. In period t, there are n_t employed

workers and $(1 - n_t)$ unemployed workers. Following Merz (1995), we assume that the family provides perfect consumption insurance for its members. Thus, consumption is the same for each member, regardless of whether she or he is employed or not.

Conditional on n_t, the household chooses consumption c_t, real money balances m_t, government bonds b_t, capital utilization u_t, investment i_t, and physical capital $\bar{k}_t$ to maximize the expected lifetime utility function

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left\{ \zeta_t \frac{(c_t - \mathfrak{h} c_{t-1})^{1-\sigma}}{1-\sigma} + \Psi \left(\frac{m_t^{1-\gamma}}{1-\gamma} \right) - v_t \Phi \int \left(n_{it} \frac{h_{it}^{1+\mu}}{1+\mu} \right) di \right\}, \tag{1}$$

where $\beta \in (0,1)$ is the household's subjective discount factor, ζ_t is a preference shock, and v_t is a labor supply shock. The parameter $\mathfrak{h}$ controls habit persistence and σ governs the degree of risk aversion. $\Psi > 0$ is a scale parameter and the parameter γ determines the elasticity of money demand. n_{it} and h_{it} are employment and hours of work at firm i in period t, respectively. $\Phi > 0$ measures the disutility of labor supply and μ is the inverse of the Frisch elasticity of labor supply.

Let P_t be the nominal price level, W_{it} be the nominal wage at firm i, z be the unemployment benefits for each unemployed worker, $r_{k,t}$ be the real rental rate of effective capital, R_{t-1} be the nominal interest rate, F_t be the dividend that the household receives from the firm sector, τ_c be the consumption tax rate, and τ_t be the lump-sum tax. Then, the household's budget constraint is

$$\begin{aligned}
(1 + \tau_c) c_t + i_t + m_t + b_t &= \int \left(n_{it} \frac{W_{it} h_{it}}{P_t} \right) di + (1 - n_t) z + r_{k,t} \left(u_t \bar{k}_{t-1} \right) \\
&\quad + \frac{m_{t-1}}{\pi_t} + \frac{R_{t-1} b_{t-1}}{\pi_t} + F_t - \tau_t - a(u_t) \bar{k}_{t-1},
\end{aligned} \tag{2}$$

where $\pi_t = p_t / p_{t-1}$ is the gross inflation rate.

The household owns capital and chooses the capital utilization rate u_t, which transforms physical capital into effective capital according to

$$k_t = u_t \bar{k}_{t-1}.$$

The cost of capital utilization per unit of physical capital is given by $a(u_t)$. We assume that $u_t = 1$ in the steady state, $a(1) = 0$ and $a'(1)/a''(1) \equiv v_a$.

The evolution of physical capital stock is given by

$$\bar{k}_t = (1 - \delta) \bar{k}_{t-1} + \varkappa_t \left(1 - \mathcal{S} \left(\frac{i_t}{i_{t-1}} \right) \right) i_t, \tag{3}$$

where δ is the depreciation rate, the function $\mathcal{S}$ captures the investment adjustment cost with $\mathcal{S}(1) = \mathcal{S}'(1) = 0$ and $S''(1) \equiv v_k > 0$, and $\varkappa_t$ is an investment-specific technology shock.[2]

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[2]Justiniano et al. (2010) demonstrate that a shock to the marginal efficiency of investment is the key driver of business cycles in the U.S. Following Justiniano et al. (2010), we incorporate the investment shock into our model.

The household's optimal decisions with respect to c_t, m_t, b_t, u_t, i_t and $\bar{k}_t$ yield

$$(1+\tau_c)\lambda_t = \zeta_t(c_t - \mathfrak{h}c_{t-1})^{-\sigma} - \beta\mathfrak{h}\mathbb{E}_t\zeta_{t+1}(c_{t+1} - \mathfrak{h}c_t)^{-\sigma},$$

$$\lambda_t = \Psi m_t^{-\gamma} + \beta\mathbb{E}_t\left(\frac{\lambda_{t+1}}{\pi_{t+1}}\right),$$

$$\lambda_t = \beta\mathbb{E}_t\left(\frac{\lambda_{t+1}R_t}{\pi_{t+1}}\right),$$

$$r_{k,t} = a'(u_t),$$

$$1 = \psi_t \varkappa_t\left\langle 1 - \mathcal{S}\left(\frac{i_t}{i_{t-1}}\right) + \mathcal{S}'\left(\frac{i_t}{i_{t-1}}\right)\frac{i_t}{i_{t-1}}\right\rangle + \beta\mathbb{E}_t\left\langle\frac{\lambda_{t+1}}{\lambda_t}\psi_{t+1}\varkappa_{t+1}\left\{\mathcal{S}'\left(\frac{i_{t+1}}{i_t}\right)\left(\frac{i_{t+1}}{i_t}\right)^2\right\}\right\rangle,$$

$$\psi_t = \beta\mathbb{E}_t\frac{\lambda_{t+1}}{\lambda_t}\left\{r_{k,t+1}u_{t+1} + \psi_{t+1}(1-\delta) - a(u_{t+1})\right\},$$

where λ_t and ψ_t are the Lagrange multipliers associated with the budget constraint (2) and the capital accumulation equation (3), respectively.

We conclude the description of the household's problem by defining the marginal value of being employed, which is useful to determine the wage.

The value of employment at firm i, $\mathcal{V}_{i,t}^E$, is given by

$$\mathcal{V}_{i,t}^E = \frac{W_{it}h_{it}}{P_t} - \frac{\Phi}{\lambda_t}\frac{h_{i,t}^{1+\mu}}{1+\mu} + \beta\mathbb{E}_t\frac{\lambda_{t+1}}{\lambda_t}\left\{(1-s)\mathcal{V}_{i,t+1}^E + s(1-f_{t+1})\mathcal{V}_{t+1}^U + sf_{t+1}\int\mathcal{V}_{j,t+1}^E dj\right\},$$

where $\mathcal{V}_t^U$ is the value of unemployment. This equation states that the marginal value of a job for a worker is composed of the real wage, the disutility from supplying labor, and the expected discounted value from being employed or unemployed in the following period.

The value of unemployment is

$$\mathcal{V}_t^U = z + \beta\mathbb{E}_t\frac{\lambda_{t+1}}{\lambda_t}\left\{(1-f_{t+1})\mathcal{V}_{t+1}^U + f_{t+1}\int\mathcal{V}_{j,t+1}^E dj\right\}.$$

The value of unemployment is given by unemployment benefits plus the expected discounted value from being either employed or unemployed in the following period.

The household's net value of employment at firm i, $\mathcal{W}_{i,t} = \mathcal{V}_{i,t}^E - \mathcal{V}_t^U$, is

$$\mathcal{W}_{i,t} = \frac{W_{it}h_{it}}{P_t} - z - \frac{\Phi}{\lambda_t}\frac{h_{i,t}^{1+\mu}}{1+\mu} + \beta(1-s)\mathbb{E}_t\frac{\lambda_{t+1}}{\lambda_t}\left(\mathcal{W}_{i,t+1} - f_{t+1}\mathcal{W}_{t+1}\right),$$

where $\mathcal{W}_{t+1} = \int\mathcal{W}_{j,t+1}dj$ is the average net asset value of being employed.

2.3 Intermediate good firms

As we explained earlier, there is a continuum of intermediate good firms, and these firms produce and sell homogenous intermediate good to wholesalers at the competitive price $p_{m,t}$. Each

period, firm i produces output by using capital and labor according to the production technology

$$y_{i,t} = A_t k_{i,t}^{\alpha} (n_{i,t} h_{i,t})^{1-\alpha},$$

where A_t is a common technology shock, $k_{i,t}$ is the level of capital, and $0 < \alpha < 1$ is the capital share.

The firm chooses its desired number of employees $n_{i,t}$, the number of vacancies $v_{i,t}$, and its level of capital $k_{i,t}$ to maximize the present value of its lifetime profits

$$\max \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \frac{\lambda_t}{\lambda_0} \left(p_{m,t} y_{i,t} - n_{i,t} \left(\frac{W_{i,t} h_{i,t}}{P_t} \right) - r_{t,t} k_{i,t} - C(v_{i,t}) \right)$$

subject to the production function and the law of motion for employment:

$$n_{i,t} = (1 - s) n_{i,t-1} + q_t v_{i,t}.$$

Since the household owns intermediate good firms, the profit flows are evaluated at the household's discount factor in terms of marginal utility λ. The wage rate and hours of work are determined through a bargaining process. Intermediate goods firms rent capital in a competitive market with real rental rate $r_{k,t}$. The cost of posting vacancies is given by $C(v_{i,t}) = c_0 v_{i,t}^{1+\gamma_v} / (1 + \gamma_v)$, where $c_0 > 0$ is a scaling factor and $\gamma_v > 0$ governs the elasticity of hiring costs with respect to vacancies.[3]

The first-order condition with respect to $k_{i,t}$ yields

$$\alpha \frac{p_{m,t} y_{i,t}}{k_{i,t}} = r_{k,t},$$

which states that the marginal revenue product of capita equals the real capital rental rate. This equation implies that the capital-labor ratio is equalized across firms $k_{i,t}/n_{i,t} h_{i,t} = k_t/n_t h_t$ for all i. Consequently, the marginal product of labor $mpl_{i,t} = (1 - \alpha) A_t (k_{i,t}/n_{i,t} h_{i,t})^{\alpha}$ is also equalized across firms. That is, $mpl_{i,t} = mpl_t$.

Let $\mathcal{J}_{i,t}$ be the Lagrange multiplier associated with the employment constraint. Then, the first-order conditions with respect to $v_{i,t}$ and $n_{i,t}$ yield

$$\mathcal{J}_{i,t} = \frac{C'(v_{i,t})}{q_t},$$

$$\mathcal{J}_{i,t} = p_{m,t}(mpl_t) h_{i,t} - \frac{W_{i,t} h_{i,t}}{P_t} + \beta(1-s) \mathbb{E}_t \frac{\lambda_{t+1}}{\lambda_t} \mathcal{J}_{i,t+1}.$$

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[3]There are two reasons why the cost of posting vacancies assumed to be convex, rather than linear as in the standard search and matching model. First, it is known that the curvature of the vacancy-posting cost affects the quantitative property of the search and matching model (Fujita and Ramey, 2007; Yahiv, 2006). Second, in order to make all firms post vacancies in an equilibrium, the convex cost of posting vacancies is needed. See Gertler and Trigari (2009) and Thomas (2008) for the detail.

Combining these two equations, we have the following job creation condition:

$$\frac{C'(v_{i,t})}{q_t} = p_{m,t}(mpl_t)h_{i,t} - \frac{W_{i,t}h_{i,t}}{P_t} + \beta(1-s)\mathbb{E}_t\frac{\lambda_{t+1}}{\lambda_t}\frac{C'(v_{i,t+1})}{q_{t+1}}.$$

The job creation condition equates the cost of hiring an additional worker with the marginal benefit that the additional worker brings into the firm.

2.4 Hours choice

Hours of work are determined by a firm and its worker in a private efficient way.[4] Thus, hours of work are chosen to maximize the joint surplus of their employment relationship:

$$\max_{h_{i,t}}(\mathcal{W}_{i,t} + \mathcal{J}_{i,t}).$$

The first-order condition yields

$$p_{m,t}(mpl_t) = \frac{\Phi}{\lambda_t}h_{i,t}^{\mu},$$

which states that hours of work are determined by equalizing the marginal revenue product of labor and the marginal rate of substitution between leisure and consumption. Since the marginal revenue product of labor is the same for all firms, the working hours are equalized across firms, $h_{it} = h_t$ for all i.

2.5 Wage bargaining

We introduce sticky nominal wages. Similar to the Calvo model of price-setting, we assume that in each period a randomly chosen fraction $1 - \varphi_w$ of firms are allowed to renegotiate nominal wages with their employees. Since there are no idiosyncratic technology shocks, firms adjusting to the new nominal wage set the same wage W_t^*. If firm i cannot renegotiate its contract with its employees, it sets nominal wage $W_{i,t}$ according to an indexation rule:

$$W_{i,t} = \bar{\gamma}\pi_{t-1}^{\iota_w}W_{i,t-1},$$

where $\bar{\gamma} = \pi^{1-\iota_w}$ and ι_w reflects the degree of indexing to past inflation.[5]

Following Thomas (2008), we assume that the negotiated wage reflects the following rule:

$$\eta\mathcal{J}_t^* = (1-\eta)\,\mathcal{W}_t^*, \tag{4}$$

where $\eta \in (0,1)$ is the worker's bargaining power and the superscript $*$ denotes renegotiating workers and firms. This sharing rule implies that renegotiating workers obtain a fraction η of the joint surplus.[6]

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[4]See Thomas (2008) and Faccini et al. (2013).

[5]In the paper, a variable without time subscript denotes its steady-state value. For example, π is the steady state gross inflation.

[6]It is important to note that this is different form Nash bargaining.

With wage stickiness, the value of employment to the renegotiating firm can be written as

$$\mathcal{J}_t^* = \bar{w}_t h_t - \frac{W_t^*}{P_t} h_t + \beta(1-s)\mathbb{E}_t \frac{\lambda_{t+1}}{\lambda_t} \left[(1-\varphi_w)\mathcal{J}_{t+1}^* + \varphi_w \mathcal{J}_{t+1}(\mathcal{X}_{t,t+1}^w W_t^*) \right], \tag{5}$$

where $\bar{w}_t = p_{m,t}(mpl_t)$ is the marginal revenue product and $\mathcal{X}_{t,t+k}^w$ captures the effect of price indexation between period t and $t+k$. It is given by

$$\mathcal{X}_{t,t+k}^w = \begin{cases} \bar{\gamma}^k \prod_{s=1}^{k} \pi_{t+s-1}^{\iota_w} & \text{if} \quad k \geq 1 \\ 1 & \text{if} \quad k = 0 \end{cases}.$$

Similarly, the value of employment in a renegotiating firm to the household can be expressed as

$$\mathcal{W}_t^* = \frac{W_t^* h_t}{P_t} - \underline{w}_t h_t + \beta(1-s)\mathbb{E}_t \frac{\lambda_{t+1}}{\lambda_t} \left[(1-\varphi_w)\mathcal{W}_{t+1}^* + \varphi_w \mathcal{W}_{t+1}\left(\mathcal{X}_{t,t+1}^w W_t^*\right) \right], \tag{6}$$

where

$$\underline{w}_t = \frac{z}{h_t} + \frac{\Phi}{\lambda_t} \frac{h_t^{\mu}}{1+\mu} + \beta(1-s)\mathbb{E}_t \frac{\lambda_{t+1}}{\lambda_t} \frac{f_{t+1}\mathcal{W}_{t+1}}{h_t}.$$

Iterating equations (5) and (6) forward, we have

$$\begin{aligned}
\mathcal{J}_t^* &= \mathbb{E}_t \sum_{k=0}^{\infty} \frac{\lambda_{t+k}}{\lambda_t} [\beta(1-s)\varphi_w]^k \left\{ \bar{w}_{t+k} h_{t+k} - \frac{\mathcal{X}_{t,t+k}^w W_t^*}{P_{t+k}} h_{t+k} \right\} \\
&\quad + \beta(1-s)(1-\varphi_w)\mathbb{E}_t \sum_{k=1}^{\infty} \frac{\lambda_{t+k}}{\lambda_t} [\beta(1-s)\varphi_w]^{k-1} \mathcal{J}_{t+k}^*,
\end{aligned}$$

and

$$\begin{aligned}
\mathcal{W}_t^* &= \mathbb{E}_t \sum_{k=0}^{\infty} \frac{\lambda_{t+k}}{\lambda_t} [\beta(1-s)\varphi_w]^k \left(\frac{\mathcal{X}_{t,t+k}^w W_t^*}{P_{t+k}} h_{t+k} - \underline{w}_{t+k} h_{t+k} \right) \\
&\quad + \beta(1-s)(1-\varphi_w)\mathbb{E}_t \sum_{k=1}^{\infty} \frac{\lambda_{t+k}}{\lambda_t} [\beta(1-s)\varphi_w]^{k-1} \mathcal{W}_{t+k}^*.
\end{aligned}$$

Combining the sharing rule (4) with the expressions for $\mathcal{J}_t^*$ and $\mathcal{W}_t^*$, we obtain the following expression for the nominal wage agreement

$$\mathbb{E}_t \sum_{k=0}^{\infty} \frac{\lambda_{t+k}}{\lambda_t} [\beta(1-s)\varphi_w]^k \left(\frac{\mathcal{X}_{t,t+k}^w P_t w_t^*}{P_{t+k}} - w_{t+k}^{tar} \right) h_{t+k} = 0, \tag{7}$$

where $w_{t+k}^{tar} = \eta \bar{w}_{t+k} + (1-\eta)\underline{w}_{t+k}$ is the real wage to which both parties would agree if wages were totally flexible and $w_t^* = W_t^*/P_t^*$ is the real wage set by renegotiating firms.

Since renegotiating firms are randomly chosen, the law of motion for the aggregate real wage is given by

$$w_t = (1-\varphi_w)w_t^* + \varphi_w w_{t-1}, \tag{8}$$

where $w_t = \int_0^1 \left(\frac{W_{it}}{P_t} \right) di$.

2.6 The final good firms

The final good is produced by combining a continuum of differentiated goods indexed by j. The production function of the final good producer is given by

$$Y_t = \left(\int_0^1 y_{j,t}^{\frac{\epsilon_t - 1}{\epsilon_t}} \, dj \right)^{\frac{\epsilon_t}{\epsilon_t - 1}}, \tag{9}$$

where $y_{j,t}$ is the quantity of output sold by wholesale firm j and ϵ_t is the elasticity of substitution across the differentiated goods.

The final good producer is perfectly competitive and maximizes real profits subject to (9), taking as given input prices $P_{j,t}$ and the final good price P_t. Thus, the problem of the final good producer is

$$\max_{y_{j,t}} Y_t - \int_0^1 \left(\frac{P_{j,t}}{P_t} \right) y_{j,t} dj.$$

This yields the demand for wholesale goods

$$y_{j,t} = \left(\frac{P_{j,t}}{P_t} \right)^{-\epsilon_t} Y_t,$$

and the aggregate price index:

$$P_t = \left(\int_0^1 P_{j,t}^{1-\epsilon_t} dj \right)^{\frac{1}{1-\epsilon_t}}.$$

2.7 Wholesalers

There is a unit measure of wholesale firms. Wholesalers buy homogenous goods from the intermediate good firms and transform them to heterogeneous goods, which are sold to final good firms. Wholesalers are monopolistic competitors and, hence, able to set the desired prices. We assume that wholesale firms are subject to price setting frictions à la Calvo (1983).[7] In each period, fraction $1 - \varphi_p$ of wholesale firms are allowed to reset the desired optimal nominal price $\tilde{P}_t$. If wholesale firms cannot set the desired optimal prices, they follow the price indexation scheme:

$$P_{j,t} = \pi_{t-1}^{\iota_p} \pi^{1-\iota_p} P_{j,t-1},$$

where π is the steady-state inflation and ι_p reflects the degree of indexing to past inflation.

If a wholesale firm is able to re-optimize its product price, it chooses the optimal price $\tilde{P}_t$ by solving the following (real) profit maximization problem:

$$\max_{\tilde{P}_t} \mathbb{E}_t \left\{ \sum_{i=0}^{\infty} \beta^{t+i} \varphi_p^i \frac{\lambda_{t+i}}{\lambda_0} \left[\frac{\tilde{P}_t \mathcal{X}_{t,i}}{P_{t+i}} - p_{m,t+i} \right] \tilde{y}_{t+i} \right\}$$

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[7]See Bernanke et al. (1998) for a similar setting. The separation between intermediate good firms and wholesalers makes it easy to analyze labor market frictions and price rigidity simultaneously.

subject to the demand function

$$\tilde{y}_{t+i} = \left(\frac{\tilde{P}_t \mathcal{X}_{t,i}}{P_{t+i}} \right)^{-\epsilon_{t+i}} Y_{t+i},$$

where $\mathcal{X}_{t,i}$ captures the effect of the price indexation between period t and period $t + i$ and is given by

$$\mathcal{X}_{t,i} = \begin{cases} \prod_{s=1}^{i} \pi_{t+s-1}^{\iota_p} \pi^{1-\iota_p} & \text{if } i \geq 1 \\ 1 & \text{if } i = 0 \end{cases}.$$

Note that future profits are discounted at the rate $\beta^{t+i} \lambda_{t+i} / \lambda_0$ since the household own wholesale firms.

The first-order condition with respect to $\tilde{P}_t$ can be expressed as

$$\mathbb{E}_t \left\{ \sum_{i=0}^{\infty} \left(\beta \varphi_p \right)^i \lambda_{t+i} \tilde{y}_{t+i} P_{t+i}^{-1} \left((1 - \epsilon_{t+i}) \tilde{P}_t \mathcal{X}_{t,i} + \epsilon_{t+i} p_{m,t+i} P_{t+i} \right) \right\} = 0. \tag{10}$$

Since firms are randomly selected to change price, the law of motion for the aggregate price is given by

$$P_t^{1-\epsilon_t} = \varphi_p \tilde{P}_t^{1-\epsilon_t} + \left(1 - \varphi_p \right) \left(P_{t-1} \pi_{t-1}^{\iota_p} \pi^{1-\iota_p} \right)^{1-\epsilon_t}. \tag{11}$$

2.8 Price and wage inflation

By using equations (7) and (8), we derive the New Keynesian Wage Phillips Curve as follows:

$$\begin{aligned}
\hat{\pi}_t^{rw} &= \beta(1-s)\mathbb{E}_t \hat{\pi}_{t+1}^{rw} + \frac{[1 - \beta(1-s)\varphi_w](1-\varphi_w)}{\varphi_w} \left(\hat{w}_t^{tar} - \hat{w}_t \right) \\
&\quad + \beta(1-s)\mathbb{E}_t \left(\hat{\pi}_{t+1} - \iota_w \hat{\pi}_t \right) - \left(\hat{\pi}_t - \iota_w \hat{\pi}_{t-1} \right),
\end{aligned}$$

where $\pi_t^{rw} = w_t / w_{t-1}$ is the real wage inflation and a "hat" denotes the variable's deviation from its steady state.

By using equations (10) and (11), we have the following New Keynesian Phillips Curve:

$$\hat{\pi}_t = \frac{\iota_p \hat{\pi}_{t-1} + \beta \mathbb{E}_t \hat{\pi}_{t+1}}{1 + \beta \iota_p} + \frac{\left(1 - \beta \varphi_p \right)(1 - \varphi_p)}{\varphi_p (1 + \beta \iota_p)} \left(\frac{1}{1 - \epsilon} \hat{\epsilon}_t + \hat{p}_{m,t} \right).$$

2.9 The government

Money is exogenously supplied by the government according to the following rule:

$$M_t = \chi_t M_{t-1},$$

12

where χ_t is the nominal money growth rate which follows

$$\log \chi_t = (1 - \rho_\chi) \log \chi + \rho_\chi \log \chi_{t-1} - \psi_\pi \log \left(\frac{\pi_t}{\pi} \right) + \varepsilon_{\chi,t}.$$

The government finances government consumption g_t and unemployment benefits $z(1 - n_t)$ by levying the lump-sum tax τ_t and the consumption tax $\tau_c c_t$ on households and issuing government bonds b_t. The government consumption g_t is assumed to be an exogenous stochastic process. The government budget constraint is given by

$$g_t + z(1 - n_t) + \frac{R_{t-1} b_{t-1}}{\pi_t} + \frac{m_{t-1}}{\pi_t} = \tau_c c_t + \tau_t + b_t + m_t.$$

2.10 Resource constraint

The resource constraint is given by

$$y_t = c_t + i_t + g_t + \frac{c_0}{1 + \gamma_v} \int v_{i,t}^{1+\gamma_v} di + a(u_t) \bar{k}_{t-1}.$$

2.11 Shocks

The description of the model is completed by specifying the properties of the shocks. There are eight shocks in the model. They are a preference shock, a markup shock, an investment shock, a technology shock, a labor supply shock, a matching shock, a government spending shock, and a monetary policy shock. All shocks, except the monetary policy shock, are assumed to follow a first-order autoregressive process:

$$\log x_t = \rho_x \log x_{t-1} + \varepsilon_{x,t},$$

where the shock $x \in \{\zeta, \epsilon, \varkappa, A, v, \vartheta, g\}$, $\rho_x \in (0,1)$ and $\varepsilon_{x,t} \sim$ i.i.d. $N(0, \sigma_x^2)$.

3 Estimation

We use Bayesian methods to estimate the model. We first log-linearize the nonlinear model around the deterministic steady state. We then solve the model and apply the Kalman filter to evaluate the likelihood function of the observable variables. The likelihood function and the prior distribution of the parameters are combined to obtain the posterior distribution. The posterior kernel is simulated numerically by employing the random-walk Metropolis-Hastings algorithm.[8]

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[8]Details on the estimation procedure can be found in An and Schorfheide (2007).

3.1 Calibrated parameters

Most parameters are estimated but some are fixed or calculated from steady-state conditions to facilitate the identification of structural parameters of interest. We calibrate the model parameters to match certain facts of Japanese economy.[9] The calibrated parameter values are parameterized at a quarterly frequency and are summarized in Table 1.

Preference   The discount factor β is set at 0.99, implying a 4% annual rate of discount for the household. We set the scale parameter for utility of holding money $\Psi = 1$ for normalization. The disutility of labor scaling parameter Φ is set so that the steady-state hours of work becomes 1/3.

Technology   The capital share of output α is set equal to 0.35. Following Sugo and Ueda (2010), we set the capital depreciation rate $\delta = 0.06$. The elasticity of demand ϵ is set to 11, which implies a steady-state markup of 10%. This is the conventional value in the literature.

Labor market and others   Following Gertler et al. (2008), the elasticity of the vacancy cost function γ_v is fixed and is set at 1.0. The job separation rate s is set to 0.012, as estimated by Miyamoto (2011) and Lin and Miyamoto (2012). The steady-state ratio of government spending to output, g/y, is set to 0.2 based on the data. The consumption tax rate τ_c is set to 0.05.

3.2 Data

The remaining parameters are estimated. For the estimation, we use observations on eight quarterly data series: (1) per capita real GDP; (2) per capita real consumption; (3) per capita real investment; (4) the nominal wage; (5) the monetary base; (6) inflation as measured by the quarter to quarter growth rate of CPI excluding fresh foods; (7) the unemployment rate; (8) the vacancy rate.

We obtain data on GDP, private consumption and investment, government spending which is sum of government consumption and investment from the Cabinet Office. The nominal wage data is obtained from the Monthly Labour Survey conducted by the Ministry of Health, Labour and Welfare (MHLW). We use hourly scheduled wages as the measure of nominal wages. The monetary base data is obtained from the Bank of Japan Statistics. We obtain CPI from the Statistics Bureau. We obtain the unemployment rate from the Labour Force Survey. The vacancy rate is obtained from the monthly Report on Employment Service (Shokugyo Antei Gyomu Tokei)

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[9]For those calibrated parameters, as much as possible, we follow parameter values which are standard in the literature.

conducted by the MHLW. All data except the monetary base are seasonally adjusted by using the Census Bureau's X12 filter. We use the CPI excluding fresh foods to convert nominal variables to real terms. All series are first logged and then de-trended using the Hodrick-Prescott filter with smoothing parameter 1600 so that every variable is expressed as percentage deviation from its trend. The sample covers the period of 1994Q1-2014Q4.

3.3 Priors

Prior distributions of parameters to be estimated are reported in Tables 2 and 3. We choose priors for the Bayesian estimation based on the typical values used in the literature. We use Beta distributions for parameters that take sensible values between zero and one, Gamma distributions for real-valued parameters, and the inverse Gamma distributions for the shock standard deviations.

Preference   The prior mean of the relative risk aversion σ is set equal to 1. Following Gertler et al. (2008), the prior mean of the habit persistence parameter $\mathfrak{h}$ is set equal to 0.5. The prior mean of the inverse of the interest elasticity of money demand γ is set at 2.0. Based on Kuroda and Yamamoto (2008), we set the prior mean for μ is 2, which implies the Frisch elasticity of 0.5.

Labor market frictions   Regarding the matching function, we set the prior of the elasticity ξ is assumed to be 0.6, as in Lin and Miyamoto (2014). The prior mean of the unemployment benefit z is chosen to match a replacement ration of 0.6, in line with the evidence in Martin (1998). The prior mean of the worker's bargaining power η is set to 0.5, such that the firm and the worker equally share their joint surplus. Regarding the scale parameter c_0 in the vacancy cost function, the prior mean is set to 1.5, which is obtained by targeting the steady-state (monthly) job finding rate of 14.2% and vacancy-unemployment ratio of 0.78.

Stickiness and technology parameters   As for priors of the elasticity of the utilization rate to the rental rate of capital ν_s and the elasticity of the capital adjustment cost function ν_a, our choice is in line with Justiniano et al. (2010). Following Gertler et al. (2008), the prior means of the Calvo parameter on prices φ_p and the partial indexation parameter for sticky price ι_p are set to 0.66 and 0.5, respectively. Following Faccini et al. (2013), we take an agnostic view on whether wages are more flexible than prices, and thus set the prior mean of the Calvo parameter on wages φ_w to 0.66. We also set the prior mean of ι_w 0.5.

Shock process   The prior means of the autoregressive parameters are set equal to 0.5 and the prior means of the standard errors are set to 1.0 for all the shocks. Regarding the monetary policy shock, the prior means of the parameter ψ_π is set equal to 1.0.

15

3.4 Posteriors

Tables 2 and 3 report the posterior means of the parameters estimated together with their 90% confidence intervals.

Preferences The posterior means of the relative risk aversion σ and the habit persistence parameter $\mathfrak{h}$ are 1.56 and 0.39, respectively. This is line with Iiboshi et al. (2006), Sugo and Ueda (2008), and Ichiue et al. (2012), who estimate a DSGE model with Japan's data. Regarding the inverse of the interest elasticity of money demand, the posterior estimate of γ is 1.49. The posterior mean of the inverse of the Frisch elasticity of labor supply μ is equal to 1.09, which is substantially smaller than the prior. This low estimate reflects the fact that intensive margin is important for employment volatility in Japan.[10]

Labor market frictions The estimate of the match elasticity ξ of 0.73 is considerably higher than the prior.[11] This value is outside the plausible range of 0.5-0.7 reported by Petrongolo and Pissarides (2001). This high estimate suggests that the number of new hires mainly depends on the number of unemployed workers rather than the number of vacancies posted. The posterior mean of the unemployment benefit z is 0.26, which is slightly higher than the prior. Regarding the worker's bargaining power, the posterior estimate of η is almost zero with a 90 percent coverage region that is concentrated and shifted away from the prior. The low worker's bargaining power implies that firms can claim virtually their entire surplus while workers are just paid the small outside benefit and compensation for the disutility of working. Our estimate is remarkably close to that of Lubik (2009) based on the U.S. data. The estimates of the scale parameter in the vacancy posting cost c_0 and the separation rate s are not identified in a purely econometric sense, since the posterior distribution overlaps with the prior. This finding is consistent with Lubik (2009, 2012) and Lin and Miyamoto (2014).

Stickiness and technology parameters Regarding the elasticities of the capital utilization rate and the capital adjustment cost function, the prior means of ν_s and ν_a are 3.67 and 6.85, respectively.

The posterior mean of the Calvo parameter φ_p is 0.79, which implies that the average contract duration of price setting is about 5 quarters. This is in line with Iiboshi et al. (2006) and Sugo and Ueda (2008) for the Japanese economy. Regarding price indexation to lagged inflation ι_p, our estimate is 0.39, which is lower than that in Iiboshi et al. (2006) and Sugo and Ueda (2008), but is higher than that of Ichiue et al. (2012).

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[10]Recently, Kudoh et al. (2015) demonstrate that the intensive margin accounts for a particularly large proportion of cyclical fluctuations in the aggregate labor input in Japan. Our result is consistent with their findings.

[11]Lin and Miyamoto (2014) estimate the matching function for the Japanese labor market, and their estimate of the elasticity of the matching function ξ is 0.6. Thus, our estimate is higher than theirs.

Regarding the degree of wage rigidity, the posterior mean of φ_w is 0.73. This implies that an average frequency of wage negotiations of about one year. Thus, wage rigidity is slightly smaller than price rigidity. Our estimate is similar to the value of 0.72 in Gertler et al. (2008) based on the U.S. data and that value of 0.63 in Faccini et al. (2013) based on the U.K. data. The posterior mean of wage indexation to lagged inflation ι_w is 0.27. This result is in contrast to the case of the U.S. economy. Gertler et al. (2008) estimated the indexing parameter of almost 1, which suggest a high degree of effective real wage rigidity. The result that wage indexation plays an important role in the US but is less important in Japan is consistent with Muto and Shintani (2014).

Model comparison   In order to assess the relevance of the nominal wage rigidity, we compute the marginal log-likelihoods for the estimated models with and without nominal wage rigidity. Table 5 reports the result. The value of the marginal log-likelihood function associated with the model with sticky wages is larger than that for the model with flexible wages. This suggests that the nominal wage rigidity is important to match the Japanese data.

4   Quantitative analysis

In this section, we use the estimated DSGE model to analyze the contribution of various structural shocks to the business cycle developments in the Japanese economy and the impulse responses to those shocks.

4.1   Variance decomposition

Table 4 reports the contribution of each structural shock to the forecast error variance of the endogenous variables at different horizons.

In the short run, output is driven primarily by preference, investment and government spending shocks. Especially, the investment shock is important and it accounts for about 30% of output variations. In medium and long run, technology and mark-up shocks are important.

Inflation is driven by technology, monetary policy, and labor supply shocks. In all horizons, these three shocks accounts for more than 80% of variation in inflation. Among them, the technology shock plays a dominant role and explains about half of inflation variations.

Turning to the determinants of the unemployment rate, we find that variations in the unemployment rate are mainly driven by matching and mark-up shocks. While the matching shock explains most of variations in the short run (about 90% on impact and 66% at horizon of 1 year), the mark-up shock accounts for most of variations in the long run. This result is similar to the findings in Lubik (2009) on the US data. The variation in the vacancy rate is mainly driven by the mark-up shock. In the short run, the monetary policy shock also affects vacancy dynamics.

4.2 Impulse response

We now study the dynamic responses of the economy to various structural shocks. In order to analyze the role of wage rigidity, we compare the responses of the model with wage rigidity to those of the otherwise identical model where wage rigidity is turned off. Figures 1-3 show the results. In each figure, the solid lines are responses of our benchmark model, and the dashed lines are those of the model without wage rigidity.

Technology shock   As seen in Table 4, our estimate suggests that the technology shock is one of main driving forces of output variations. Also, the technology shock is treated as the main driving force in the literature on the unemployment volatility puzzle.[12] Therefore, we begin with this shock. Figure 1 plots the impulse responses of relevant variables to a one standard deviation technology shock. The positive technology shock increases output. The price inflation initially falls but increases after a few periods, which reduces the real interest rate. In turn, consumption and investment increase. The positive technology shock increases both the marginal product of labor and the real wage. Since the marginal product of labor increases more than the real wage, a firm has incentive to post more vacancies, which lowers unemployment.

We now investigate the role of sticky wages for the transmission of the technology shock. The qualitative responses of the variables to the technology shock in the model with flexible wages are similar to those in the model with sticky wages. However, the reaction of labor market variables in the model with staggered wages is smaller than that in the model with flexible wages.

This can be understood by seeing the response of real wages. The positive shock increases real wages in both models with and without wage rigidity, but the increase in real wages is more persistent in the model with nominal wage rigidity. This difference affects the reaction of labor market variables to the technology shock. The persistent response of real wages in the model with wage rigidity implies a smaller response of profits to the technology shock than otherwise. This leads to a smaller response of vacancies and unemployment relative to the flexible wage case.

Interestingly, this result is in contrast to Gertler et al. (2008) which demonstrate that the model with nominal wage rigidity has a greater response of labor market variables to the technology shock than the model without does for the U.S. This is because the degree of wage indexation differs between Japan and the U.S. The degree of wage indexation in Japan is much lower than that in the U.S. This implies that the degree of real wage rigidity in Japan is also much lower than that in the U.S. Flexible real wages lead to a smaller response of profits to the shock, and thus a smaller response of labor market variables.

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[12]See for example, Shimer (2005), Hall (2005), and Hagedorn and Manovskii (2008).

Investment shock   We next turn to the investment shock. Figure 2 plots impulse responses to a one standard deviation investment shock. Following a positive investment shock, output and investment rise. The response of investment is contemporaneous and roughly similar to that of output, but larger by a factor of almost three. While investment and output rise immediately after the shock, consumption increases only after a few periods. This is because the investment shock accounts for the small portion of consumption movements. This result is in line with Justiniano et al. (2010). Turning to labor market variables, firms increase their labor inputs along both the intensive and extensive margin to increase production. This leads to a lower unemployment rate. The positive investment shock increases both price inflation and the nominal wage. After the shock, the inflation rate rises immediately and then turns to decline. In contrast, the nominal wage does not respond initially and then increases. As a result, the real wage initially falls but eventually starts to increase.

Similar to the case of the technology shock, nominal wage rigidity does not affect the qualitative responses of endogenous variables except nominal wage inflation. However, it affects the quantitative responses of labor market variables to the shock. The quantitative responses of labor market variables in the model with wage rigidity are smaller than those in the model with flexible wages.

Monetary policy shock   Figure 3 displays the impulse responses of relevant variables to an expansionary monetary shock. A money injection increases price inflation. In turn, the resulting decrease in the real interest rate boosts consumption and investment. In order to increase production, firms increase hours of work and employed workers by posting more vacancies, which lowers unemployment. Increased demand puts upward pressure on the prices of production factors, which leads to higher wage and price inflation. Since the nominal wage is sluggish, the nominal wage does not rise as much as the inflation does, and thus the real wage falls.

Except real wages, qualitative responses of the variables in the model with flexible wages are similar to those of the model with sticky wages. While real wage falls in response to the monetary policy shock in the model with sticky wages, real wages rises in the model with flexible wages. This can be explained as follows. The positive monetary policy shock increases both price inflation and nominal wages. When nominal wages are flexible, nominal wages rise at a faster pace than prices, and thus real wages rise. In contrast, with sticky wages, the positive effect of the monetary policy shock on nominal wages is mitigated and the pace of nominal wages growth becomes slower than that of price inflation. Thus, real wages falls in response to the monetary policy shock.

Equally important, wage rigidity affects the quantitative responses of labor market variables to the positive monetary policy shock. The reaction of hours of work, vacancies, unemployment in the model with sticky wages is larger than that in the model with flexible wages. This is because the expansionary monetary policy shock reduces real wages in the model with wage

rigidity, which leads to a higher response of profits and thus labor market variables.

5 Discussion

This section evaluates the robustness of our results by changing data for the estimation. We first estimate our model by using different data on wages. We then estimate the model by changing the sample period of the data.

5.1 The data on nominal wages

In the benchmark case, we use scheduled wages as the observable of nominal wages. In Japan, payments to a typical worker are divided into two categories: scheduled wages and special cash earnings (bonuses). Scheduled wages are referred to base wages. However, it is well known that in Japan, bonuses make up a relatively high proportion of total payments and are more cyclical than base wages. So, it is important to take bonuses into account for wage dynamics in Japan.

We now estimate our model by using data on total cash earnings instead of scheduled wages for the robustness check. Table 6 reports the posterior means of the estimated parameters. The values of estimated parameters are almost the same to the benchmark case with exception of parameters on wage rigidity, wage indexation, and wage bargaining. The estimates of φ_w and ι_w are 0.46 and 0.46, respectively. This suggests that the average duration of wage contracts is about a half year and the degree of indexing of wages to past inflation is mild. In the benchmark case, the estimate of φ_w and ι_w are 0.73 and 0.27, respectively. Thus, when total cash earnings are used to estimate the model, nominal wages becomes more flexible and the wage indexation becomes more important. This implies that Japanese firms maintain a high degree of nominal wage flexibility by adjusting bonus payments. Thus, the model captures the important aspect of the Japanese labor market. The estimate of worker's wage bargaining power η is 0.038, which is more than twice as much as one in the benchmark case.

5.2 Sample period

In the benchmark case, we estimate our model by using the data covering the period from 1994Q1 to 2014Q4, which include the period during which the Bank of Japan adopted a zero-interest rate policy (ZIRP). Recently, Hirose and Inoue (2015) demonstrate that a standard sticky-price DSGE model missing the zero lower bound constraint (ZLBC) on the nominal interest rate does not cause significant biased estimates of parameters but causes biased estimates of structural shocks. Therefore, we now estimate our model by using the data of 1980Q1-1998Q4. The end of this sample period is determined to avoid imposing the ZLBC.

The posterior means of estimated parameters are reported in Table 6. Most of the estimated parameter values are similar to those in the benchmark case. However, parameters of wage

rigidity, wage indexation, and the worker's bargaining power are different from the benchmark. The estimates of φ_w and ι_w are 0.24 and 0.50, respectively. Since $\varphi_w = 0.73$ and $\iota_w = 0.27$ in the benchmark case, this result suggests that during the period of the so-called "lost two decades", the wage dynamic become less flexible. The estimated value of η is 0.028, which is higher than one in the benchmark. This implies that the worker's bargaining power becomes weaker in recent years.

6 Conclusion

This paper develops and estimates a DSGE model with labor market frictions and nominal wage rigidity for Japan's economy. We estimate important structural parameters that characterize the Japanese economy. This allows us to examine the transmission mechanism of various structural shocks on the economy. We also analyze how wage rigidity affects the transmission mechanism.

We find that nominal wage rigidity is important to capture Japan's economy. Our analysis demonstrates that the model with wage rigidity matches the data more closely than the model without wage rigidity does. We also find that wage rigidity is irreverent to inflation dynamics, but is affects the behavior of nominal and real wages considerably. Furthermore, wage rigidity has an strong impact on the responses of labor market variables to structural shocks. Specifically, facing a technology shock, the responses of unemployment and vacancies in the model with nominal wage rigidity are milder than those in the model with completely flexible wage contracts. This is in contrast to Gertler et al. (2008) that find the quantitative response of labor market variables to the technology shock are amplified in the model with nominal wage rigidity.

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Table 1: Calibrated parameter values

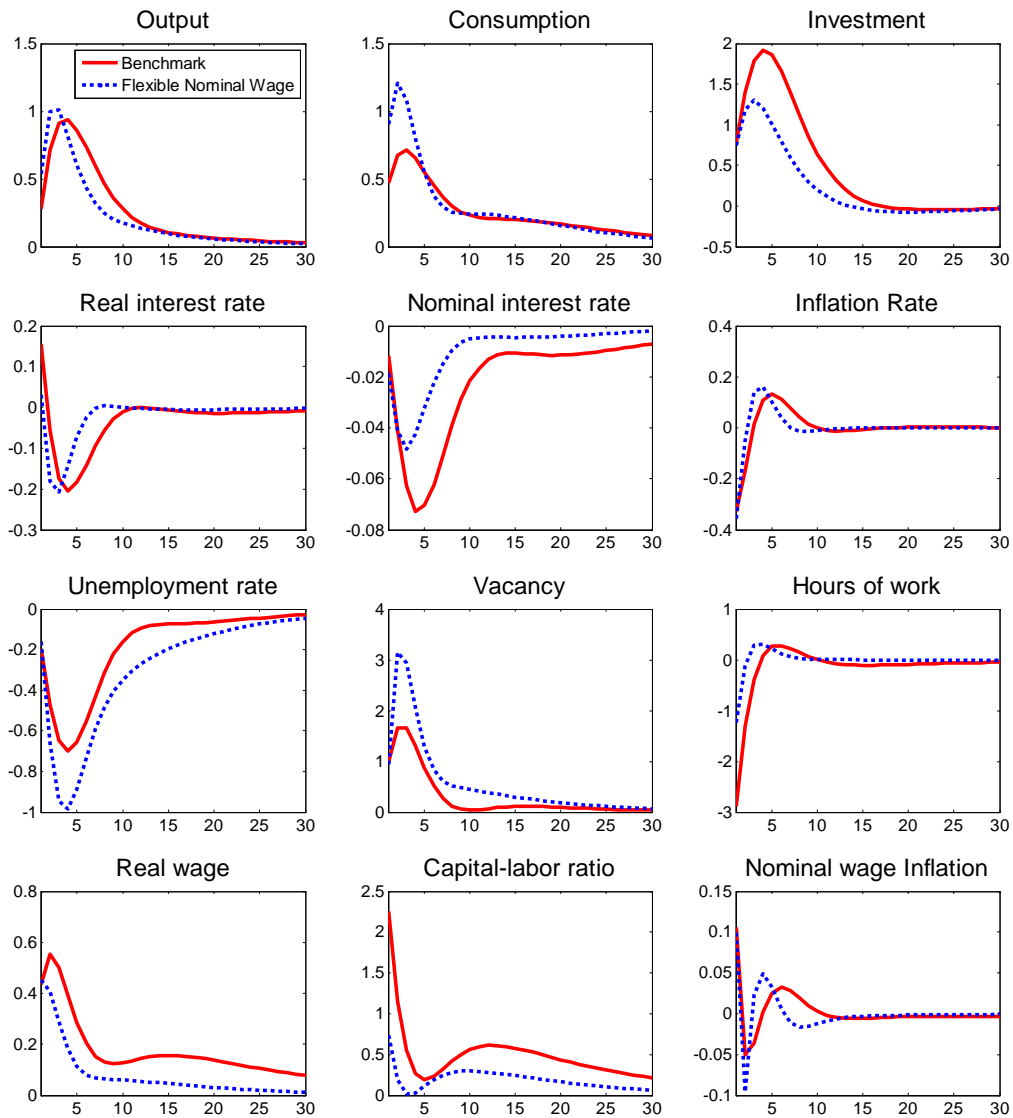| Parameter	Description	Calibrated value
β	Discount factor	0.99
Ψ	Scale parameter of the utility of holding money	1.0
Φ	Scale parameter of the labor disutility	29.58
α	Capital share	0.35
δ	Deprecation rate	0.06
ϵ	Elasticity of demand	11
γ_v	Elasticity of vacancy costs	1.0
s	Separation rate	0.012
π	Steady state gross inflation rate	1.0
τ_c	Consumption tax rate	0.05

Figure 1: Impulse responses to a positive technology shock

Note: The solid lines labeled "Benchmark" plot the impulse responses obtained in the model with sticky wages. The dashed lines labeled "Flexible Nominal Wage" plot the impulse responses obtained in the model with flexible wages. The horizontal axis represents months after the shock. The vertical axis represents percentage deviations from the steady-state value.
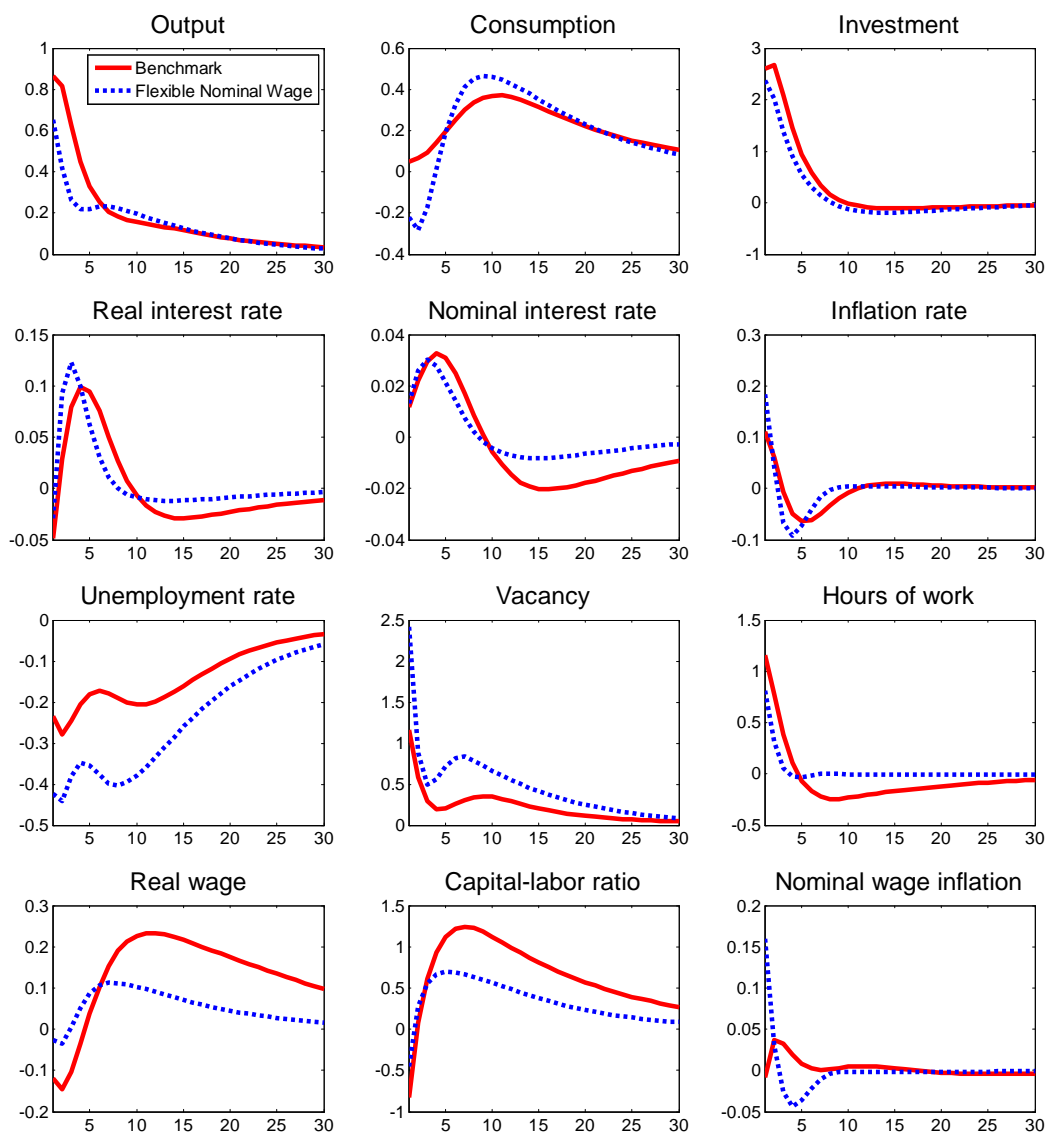
Figure 2: Impulse responses to an investment shock

Note: The solid lines labeled "Benchmark" plot the impulse responses obtained in the model with sticky wages. The dashed lines labeled "Flexible Nominal Wage" plot the impulse responses obtained in the model with flexible wages. The horizontal axis represents months after the shock. The vertical axis represents percentage deviations from the steady-state value.
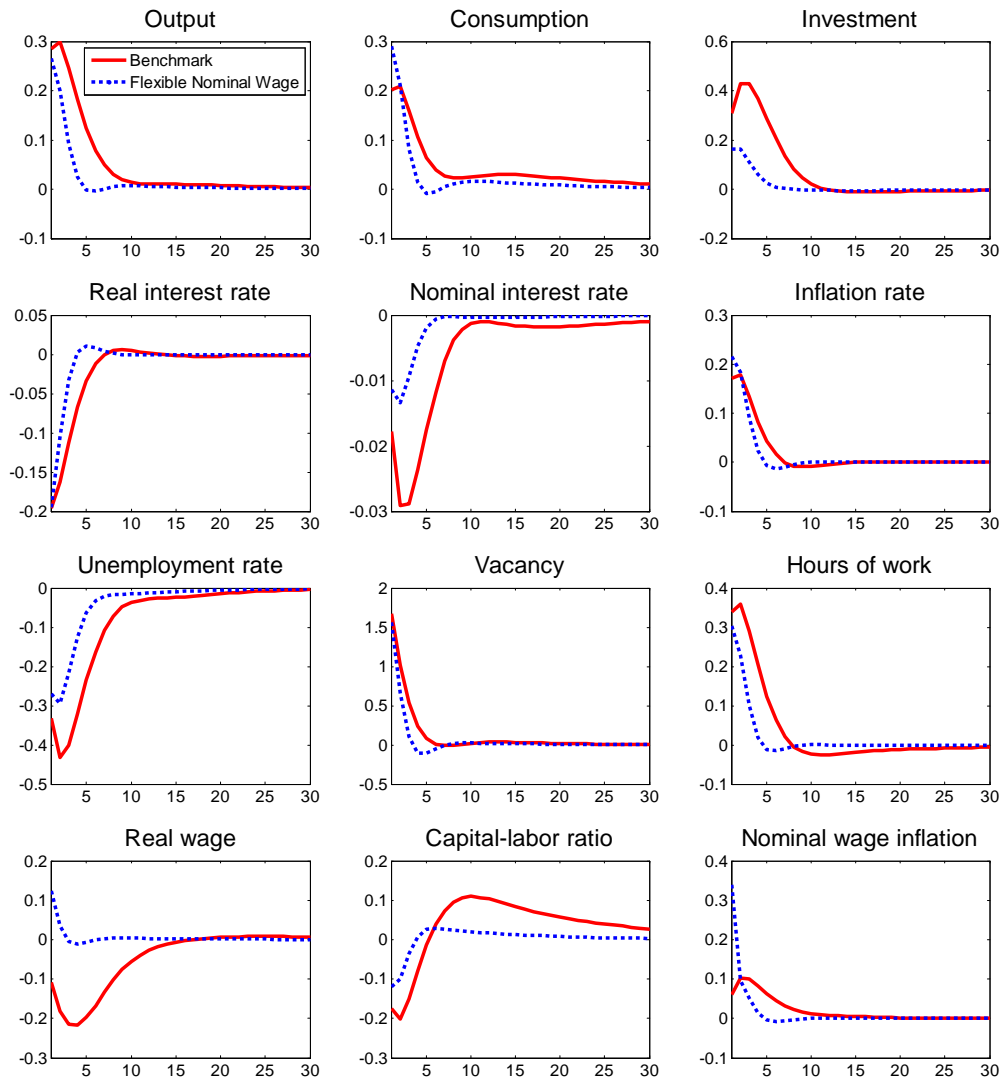
Figure 3: Impulse responses to an expansionary monetary policy shock

Note: The solid lines labeled "Benchmark" plot the impulse responses obtained in the model with sticky wages. The dashed lines labeled "Flexible Nominal Wage" plot the impulse responses obtained in the model with flexible wages. The horizontal axis represents months after the shock. The vertical axis represents percentage deviations from the steady-state value.

Table 2: Prior and Posterior Distribution of Structural Parameters

Parameter	Description	Prior			Posterior	
		Dist.	Mean.	Std. Dev.	Mean	90% Interval
σ	Relative risk aversion	G	1.0	0.5	1.559	[0.809, 2.321]
h	Habit persistency	B	0.5	0.1	0.390	[0.251, 0.529]
γ	The inverse of the interest elasticity of money demand	G	2.0	0.5	1.488	[0.875, 2.139]
μ	Frisch elasticity	G	2.0	0.5	1.087	[0.666, 1.522]
ξ	Matching elasticity	B	0.6	0.1	0.732	[0.682, 0.779]
z	Unemployment benefit	B	0.25	0.05	0.260	[0.226, 0.294]
η	Worker's bargaining power	B	0.5	0.2	0.015	[0.002, 0.028]
c_0	Scale parameter in the vacancy cost function	G	1.5	0.1	1.498	[1.335, 1.661]
ν_s	Investment adjustment cost parameter	G	4.0	1.0	3.665	[2.162, 5.067]
ν_a	Capital utilization parameter	G	5.0	1.0	6.847	[5.151, 8.616]
φ_p	Calvo price parameter	B	0.66	0.15	0.794	[0.758, 0.833]
φ_w	Calvo wage parameter	B	0.66	0.15	0.733	[0.685, 0.783]
ι_p	Price indexing parameter	B	0.5	0.1	0.394	[0.238, 0.551]
ι_w	Wage indexing parameter	B	0.5	0.1	0.272	[0.174, 0.376]
ψ_π	Monetary policy shock	G	1.0	0.5	3.107	[2.362, 3.777]

Table 3: Prior and Posterior Distribution of Shock Parameters

Parameter	Description	Prior			Posterior	
		Dist.	Mean.	Std. Dev.	Mean	90% Interval
Autoregressive parameter						
ρ_ζ	Preference	B	0.5	0.2	0.505	[0.267, 0.741]
ρ_ϵ	Mark-up	B	0.5	0.2	0.977	[0.956, 0.998]
ρ_χ	Investment	B	0.5	0.2	0.324	[0.131, 0.509]
ρ_A	Technology	B	0.5	0.2	0.679	[0.581, 0.779]
ρ_υ	Labor supply	B	0.5	0.2	0.652	[0.475, 0.828]
ρ_ϑ	Matching	B	0.5	0.2	0.200	[0.059, 0.335]
ρ_g	Government spending	B	0.5	0.2	0.610	[0.473, 0.744]
ρ_χ	Monetary policy	B	0.5	0.2	0.782	[0.645, 0.917]
Standard deviations						
σ_ζ	Preference	IG	1.0	5.0	2.682	[1.470, 3.848]
σ_ϵ	Mark-up	IG	1.0	5.0	8.271	[4.684, 11.748]
σ_χ	Investment	IG	1.0	5.0	9.9656	[5.368, 14.454]
σ_A	Technology	IG	1.0	5.0	2.484	[1.755, 3.157]
σ_υ	Labor supply	IG	1.0	5.0	6.106	[4.099, 8.063]
σ_ϑ	Matching	IG	1.0	5.0	3.137	[2.723, 3.527]
σ_g	Government spending	IG	1.0	5.0	4.317	[3.747, 4.859]
σ_χ	Monetary policy	IG	1.0	5.0	1.977	[1.683, 2.274]

Table 4: Variance decomposition

		Technology	Matching	Preference	Investment	Mark-up	Government	Monetary	Labor supply
Output	1 quarter	4.3	0.0	23.0	31.0	2.0	32.0	2.2	1.4
	1 year	32.4	0.0	10.4	22.0	3.7	10.6	1.9	13.6
	3 year	38.6	0.0	6.5	15.7	9.2	6.5	1.3	15.8
	Long run	28.6	0.0	4.7	11.8	28.8	4.6	0.9	11.3
Inflation	1 quarter	55.5	0.0	2.6	5.0	0.0	2.6	7.5	24.3
	1 year	50.6	0.0	2.8	5.0	0.1	2.3	14.6	21.8
	3 year	51.0	0.0	3.0	6.8	0.1	2.3	11.9	21.7
	Long run	50.9	0.0	3.0	6.9	0.1	2.3	11.8	21.7
Unemployment	1 quarter	0.7	90.3	0.0	0.7	6.4	0.0	1.0	0.0
	1 year	6.6	65.8	0.1	1.2	39.5	0.1	1.1	5.2
	3 year	7.5	41.1	0.1	1.2	39.5	0.1	1.1	5.2
	Long run	4.0	23.0	0.1	0.9	65.9	0.0	0.6	2.9
Vacancy	1 quarter	7.2	2.7	0.2	7.6	67.3	0.3	10.5	0.5
	1 year	19.5	1.1	0.4	3.1	57.8	0.3	4.8	10.5
	3 year	14.1	0.8	0.3	2.8	67.0	0.2	3.1	9.2
	Long run	7.4	0.4	0.2	1.7	81.5	0.1	1.6	5.0

Table 5: Marginal log-likelihood function

Benchmark	Flexible wage model
-1204.9	-1247.6

Table 6: Robstness check

Parameter	Description	Benchmark	Wage data change	Sample period change
σ	Relative risk aversion	1.559	1.600	3.219
h	Habit persistency	0.390	0.398	0.399
γ	The inverse of the interest elasticity of money demand	1.488	1.482	1.541
μ	Frisch elasticity	1.087	1.118	0.900
ξ	Matching elasticity	0.732	0.745	0.753
z	Unemployment benefit	0.260	0.271	0.267
η	Worker's bargaining power	0.015	0.038	0.028
c_0	Scale parameter in the vacancy cost function	1.498	1.497	1.503
ν_s	Investment adjustment cost parameter	3.665	3.496	3.964
ν_a	Capital utilization parameter	6.847	6.646	6.259
φ_p	Calvo price parameter	0.794	0.778	0.792
φ_w	Calvo wage parameter	0.733	0.455	0.236
ι_p	Price indexing parameter	0.394	0.373	0.330
ι_w	Wage indexing parameter	0.272	0.461	0.499
ψ_π	Monetary policy shock	3.107	3.098	2.562