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Abstract

We estimate a New Keynesian Phillips curve (NKPC) in Japan, focusing on the measurement of real marginal cost (RMC). Especially, we correct labor share by taking account of two kinds of labor market frictions: (i) labor adjustment costs and (ii) real wage rigidity. Our results show that the consideration of these labor market frictions greatly improves the fit of Japan's NKPC. Furthermore, if we additionally incorporate materials prices in the calculation of RMC, then the fit of the NKPC is further improved. Our most important finding is that the conventional backward-looking component is no more needed to explain Japan's inflation dynamics if we use a corrected measure of RMC.

Keywords: New Keynesian Phillips Curve, Real Marginal Cost, Labor Adjustment Cost, Materials Price, Real Wage Rigidity, Inflation Persistence.

JEL Classification: E31

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1 Introduction

The New Keynesian Phillips curve (NKPC), which was developed most notably by Rotemberg (1982a) and Calvo (1983), holds a central place in the recent monetary economics. Yet, despite its theoretical importance, empirical studies do not necessarily assess the NKPC as a good description of actual inflation dynamics. In relatively earlier studies, such as Galí and Gertler (1999), Galí, Gertler, and López-Salido (2001), and Sbordone (2002), there has been some consensus that the fit of the NKPC in the U.S. or the Euro area is good if we use labor share (real unit labor cost) as the proxy for real marginal cost (RMC). However, the more recent studies by Rudd and Whelan (2005a,b, 2006, 2007) show that there is scarce evidence on the correlation between inflation rate and the discounted sum of future labor shares as for the U.S. economy. They also show that the observed good performance of the "hybrid" NKPC, which introduces lagged inflation term as an additional explanatory variable, is just brought by lagged inflation, not by the discounted sum of future labor shares.[1] These results imply that the fit of the NKPC is actually poor, and that a backward-looking component plays a more important role in explaining the actual inflation dynamics.

Nevertheless, we can further consider the possibility that the fit of the NKPC is poor only because labor share is not a good proxy for RMC. Rotemberg and Woodford (1999) explain that "while labor share (or equivalently, the ratio of price to unit labor cost) is a familiar and easily interpretable statistic, it represents a valid measure of markup variations only under relatively special assumptions" (p. 1064). They show that some corrections to labor share would be required to obtain a more realistic measure of RMC, and these corrections would imply that RMC is more pro-cyclical than labor share. In the context of the NKPC, Wolman (1999) suggests that "continued progress in empirical evaluation of sticky-price models will require intensive study of the factors determining real marginal cost. With more refined estimates of real marginal cost, it may be possible to reconcile a plausible sticky-price specification with data on inflation".[2]

To apply these ideas, we estimate the NKPC for Japan's economy, focusing on the measurement of RMC. To obtain a better proxy for RMC, we correct labor share by taking account of two kinds of labor market frictions: (i) labor adjustment costs and (ii) real wage rigidity. This can be done because we have a direct measure on the degree of labor market frictions in Japan. As an extension, we also incorporate materials prices in the calculation of RMC, following Batini, Jackson, and Nickell (2005).[3]

Our exercise shows that the fit of the NKPC is poor in Japan if we naively use labor share as the proxy for RMC. This result is just the same as the U.S. or the Euro area. However, the consideration of the two kinds of labor market frictions greatly improves the fit of Japan's NKPC. Furthermore, if we incorporate materials prices, the fit of the NKPC is further improved. Our most important finding is that the inclusion of lagged inflation term into the NKPC does not improve the fit of the NKPC at all. This result indicates that the conventional backward-looking component is no more needed to explain Japan's inflation dynamics if we use a corrected measure of RMC.

Our study contributes to the literature in three respects. First, we provide a formal assessment on the empirical performance of the NKPC in Japan, which has been scarcely reported in previous studies. Second, we give an evidence that the fit of the NKPC can be underestimated due to the problem that labor share does not correctly capture the movement of RMC. Third, we show that the role of a backward-looking component can be overestimated due to the discrepancy between labor share and RMC. These findings imply that the argument of Rotemberg and Woodford

(1999) is relevant for evaluating the performance of the NKPC, as is predicted by Wolman (1999).

The rest of this study is organized as follows. In Section 2, we present the form of the NKPC under alternative measures of RMC. In Section 3, we estimate the NKPC by using Japanese data. In Section 4, we examine the role of a backward-looking component in explaining Japan's inflation dynamics. In Section 5, we give concluding remarks.

2 The NKPC under Alternative Measures of RMC

In this section, we present the form of the NKPC under alternative measures of RMC.

2.1 The Benchmark NKPC

To derive the NKPC as simply as possible, we introduce Rotemberg's (1982a,b) quadratic price adjustment cost function. The representative firm sets the price (P_t) to minimize the discounted sum of the quadratic price adjustment costs as follows:

$$E_t \sum_{k=0}^{\infty} \beta^k \left[(\ln P_{t+k} - \ln P^*_{t+k})^2 + \gamma(\ln P_{t+k} - \ln P_{t+k-1})^2 \right], \tag{1}$$

where P^*_t is the optimal price at t under flexible prices. Under monopolistic competition, P^*_t is given by

$$P^*_t = \mu MC_t, \tag{2}$$

where μ is the so-called *desired markup* (or *equilibrium markup*), which is determined by the competitiveness of the goods market, and MC_t is the nominal marginal cost.[4]

If the nominal marginal cost is given, then firms' cost minimization yields the

NKPC as follows:

$$\pi_t = \beta E_t \pi_{t+1} + \frac{1}{\gamma} \ln \mu + \frac{1}{\gamma} \ln RMC_t, \tag{3}$$

where π_t is the inflation rate and RMC_t is the real marginal cost ($RMC_t \equiv \frac{MC_t}{P_t}$).

In estimating the NKPC, we need to have the proxy for RMC. Consider the following aggregate production function, which is isoelastic with respect to the aggregate labor input (L_t):

$$Y_t = A_t L_t^{\alpha}, \tag{4}$$

where Y_t is the aggregate value added and A_t is the exogenous shift factor.[5]

Suppose that firms do not incur any adjustment cost in changing the number of labor input. Then, the real marginal cost is simply calculated as follows:

$$RMC_t = \frac{\partial(\frac{W_t}{P_t} L_t)}{\partial Y_t} = \frac{1}{\alpha} S_t, \tag{5}$$

where W_t is the nominal wage rate and S_t is labor share ($S_t \equiv \frac{W_t L_t}{P_t Y_t}$). Therefore, RMC becomes proportional to labor share.

From (3) and (5), the NKPC is expressed as follows:

$$\pi_t = \beta E_t \pi_{t+1} + \frac{1}{\gamma} \ln \frac{\mu}{\alpha} + \frac{1}{\gamma} \ln S_t. \tag{6}$$

We regard (6) as the benchmark representation of the NKPC.

2.2 The NKPC with Labor Market Frictions

Next, we derive the representation of the NKPC in the presence of two kinds of labor market frictions, such as (i) labor adjustment costs and (ii) real wage rigidity.

Suppose that, at period t, the representative firm incurs nominal adjustment costs (defined as Ω_t) in changing the number of workers. Rather than specifying the exact form of Ω_t, we only assume that Ω_t is a differentiable function of current and past labor input ($\Omega_t = \Omega_t(L_t, L_{t-1}, L_{t-2}, \cdots)$).[6,7] Since Ω_t inter-temporally depends on labor input, the firm's cost-minimization problem becomes dynamic. Then RMC at period t is calculated as follows:

$$RMC_t = \frac{1}{\alpha} S_t \left[1 + \frac{1}{W_t} E_t \sum_{k=0}^{\infty} \beta^k \left(\frac{\partial \Omega_{t+k}}{\partial L_t} \mid_{L_{t+k}=L^*_{t+k} \ \forall \ k} \right) \right], \tag{7}$$

where L^*_t is the optimal number of workers under flexible prices.

Note that, except for the special case where the sum of discounted marginal labor adjustment costs is zero ($E_t \sum_{k=0}^{\infty} \beta^k \left(\frac{\partial \Omega_{t+k}}{\partial L_t} \mid_{L_{t+k}=L^*_{t+k} \ \forall \ k} \right) = 0$), RMC does not generally correspond to labor share. Therefore, to obtain a proxy for RMC, we need to have the information on the sum of discounted marginal labor adjustment cost.

In the case of Japan, we can obtain this information from the survey data of Japanese firms. Figure 1 shows the diffusion index of employment (employment DI) in the Bank of Japan's *Short-Term Economic Survey of Enterprises in Japan* (called the *TANKAN* Survey).[8] The employment DI shows the net percentage of firms which consider that the current number of workers is excessive. As this series indicates, there has been a substantial *labor gap*, which is defined as the deviation of the actual number of workers from the optimal number of workers, for many periods. We view that the series of labor gap implies the presence of labor adjustment costs based on the reasoning that the firms can always attain the optimal number of workers if labor adjustment costs are absent. Therefore, we utilize this information to estimate the size of labor adjustment costs.

To utilize the series of the labor gap in estimating labor adjustment costs, we need to specify the process of real wage determination because the theoretical relationship between the labor gap and labor adjustment costs crucially depends on this process. In this respect, we take account of the presence of real wage rigidity, by introducing the partial adjustment process of real wages, which is adopted by Blanchard and Galí (2007) and Christoffel and Linzert (2005):

$$\ln \frac{W_t}{P_t} = \rho \ln \frac{W_{t-1}}{P_{t-1}} + (1-\rho) \ln Y_t^{\sigma} L_t^{\eta-1}. \tag{8}$$

In (8), $Y_t^{\sigma} L_t^{\eta-1}$ is the representative household's marginal rate of substitution (MRS) between consumption and labor supply under the standard instantaneous utility function ($U_t = \frac{Y_t^{1-\sigma}}{1-\sigma} - \frac{1}{\eta} L_t^{\eta}$). ρ characterizes the degree of real wage rigidity. Except for the limiting case of perfectly flexible real wage ($\rho = 0$), real wage becomes more sluggish than MRS.[9] Blanchard and Galí (2007) explain that the specification is "an admittedly ad-hoc but parsimonious way of modeling the slow adjustment of wages to labor market conditions". Note that, in Appendix C, we check the robustness of our analysis by introducing a micro-founded model of staggered real wage setting, which is presented in the Appendix B of Blanchard and Galí (2007).

Under the process of (8), we can show that RMC in the presence of labor market frictions is calculated as follows (see Appendix A):

$$\begin{aligned} \ln RMC_t \;\; &= \;\; \ln \frac{1}{\alpha} + \ln S_t + \left[\alpha - 1 - \frac{(\alpha\sigma + \eta - 1)(1-\rho)}{1-\rho B} \right] \\ & \quad \left[(1+\gamma+\gamma\beta) LGAP_t^s - \gamma LGAP_{t-1}^s - \gamma\beta E_t LGAP_{t+1}^s \right], \end{aligned} \tag{9}$$

where $LGAP_t^s$ is the labor gap under sticky prices and B is backshift operator.[10]

By substituting (9) into (3), we obtain the following representation of the NKPC in the presence of labor market frictions:

$$\pi_t = \beta E_t \pi_{t+1} + \frac{1}{\gamma} \ln \frac{\mu}{\alpha} + \frac{1}{\gamma} \ln S_t + \frac{1}{\gamma} \left[\alpha - 1 - \frac{(\alpha\sigma + \eta - 1)(1-\rho)}{1-\rho B} \right] \left[(1+\gamma+\gamma\beta) LGAP_t^s - \gamma LGAP_{t-1}^s - \gamma\beta E_t LGAP_{t+1}^s \right]. \quad (10)$$

2.3 The NKPC with Labor Market Frictions and Materials Prices

So far, we have not explicitly considered the influence of materials prices in the calculation of RMC. However, Batini, Jackson, and Nickell (2000, 2005) show that, if production technology requires a certain amount of materials to produce one additional unit of gross output, materials prices might influence RMC on value added. They consider the following production function of gross output:

$$Q_t = \min \left(A_t L_t^{\alpha},\ M_t \right), \quad (11)$$

$$M_t = m(Q_t) Q_t, \text{ where } m'(Q_t) \geq 0, \quad (12)$$

where Q_t is gross output and M_t is material input, each is represented in real terms.

(11) is the standard Leontief production technology of gross output, in which value added and material input are perfect complements. The unique contribution of Batini, Jackson, and Nickell (2000, 2005) is the introduction of (12). (12) means that the required ratio of material input to gross output (m) depends on the level of gross output (Q_t).[11]

In this setup, Batini, Jackson, and Nickell (2000, 2005) show that RMC additionally includes the following term:

$$\zeta_t = \varepsilon_m \frac{P_{M,t} M_t}{P_t Q_t}, \tag{13}$$

where $P_{M,t}$ is the price of materials and ε_m is the elasticity of M_t/Q_t to Q_t.

Then, the representation of the NKPC is modified as follows:

$$\begin{aligned} \pi_t \;\; = \;\; & \beta E_t \pi_{t+1} + \frac{1}{\gamma} \ln \frac{\mu}{\alpha} + \frac{1}{\gamma} \ln(S_t + \zeta_t) + \frac{1}{\gamma} \left[\alpha - 1 - \frac{(\alpha\sigma + \eta - 1)(1-\rho)}{1 - \rho B} \right] \\ & \left[(1 + \gamma + \gamma\beta) LGAP_t^s - \gamma LGAP_{t-1}^s - \gamma\beta E_t LGAP_{t+1}^s \right]. \end{aligned} \tag{14}$$

3 Estimating Japan's NKPC

In this section, we estimate Japan's NKPC under alternative measures of RMC. To this end, we use the present value model (PVM), which is employed by Rudd and Whelan (2005a,b, 2006, 2007).[12]

3.1 The Benchmark NKPC

Firstly, we apply the PVM for the estimation of the benchmark NKPC. In the PVM, we estimate the closed form solution of the NKPC. The closed form solution of the benchmark NKPC (6) is given by:

$$\pi_t = \frac{1}{\gamma(1-\beta)} \ln \frac{\mu}{\alpha} + \frac{1}{\gamma} E_t \sum_{k=0}^{\infty} \beta^k \ln S_{t+k}. \tag{15}$$

To construct the discounted sum of the expected (log of) labor share, we develop an auxiliary VAR as follows:

$$\mathbf{Z}_t = \mathbf{A}\mathbf{Z}_{t-1} + \boldsymbol{\epsilon}_t, \tag{16}$$

where $\mathbf{Z}_t$ is the vector of endogenous variables, $\mathbf{A}$ is a parameter matrix, and $\boldsymbol{\epsilon}_t$ is the vector of exogenous shocks. (16) represents a general form of VAR. As for the benchmark NKPC, we assume that $\mathbf{Z}_t$ includes $\ln S_t$ as the first variable.

The discounted sum of the expected (log of) labor share can be written as:

$$\sum_{k=0}^{\infty} \beta^k E_t \ln S_{t+k} = e_1'(\mathbf{I} - \beta\mathbf{A})^{-1}\mathbf{Z}_t, \tag{17}$$

where e_1' is a vector with one in the first row and zeros elsewhere. Then, the closed-form solution of the NKPC is re-expressed as

$$\pi_t = a_0 + a_1 e_1'(\mathbf{I} - \beta\mathbf{A})^{-1}\mathbf{Z}_t, \tag{18}$$

where $a_0 = \frac{1}{\gamma(1-\beta)} \ln \frac{\mu}{\alpha}$ and $a_1 = \frac{1}{\gamma}$. This is the estimation form of the benchmark NKPC. We can simply estimate (18) by ordinary least squares (OLS).[13]

In estimating the auxiliary VAR, we select some specifications of Woodford (2001) and Rudd and Whelan (2005). Put concretely, we use one univariate model, which only includes the (log of) labor share, and two multivariate models, which additionally introduce the growth rate of unit labor cost and inflation rate.[14] The lag length is chosen by Schwarz's information criterion. Following the literature, β is set as 0.99 throughout this study. The sample period is 1975/Q1-2004/Q4. See Appendix B for the data description.

Table 1 summarizes the estimation results. For each VAR specification, the fit of the NKPC is poor, since *Adj*-R^2 is just around 0.1 or 0.2 and there is noticeable serial correlation in the error term.[15] In Figure 2, we can graphically confirm the poor fit of the benchmark NKPC. It cannot explain the inflationary pressure in the late 1980s and the deflationary trend since the beginning of 1990s.

This finding raises two possibilities. The first is that the NKPC is not a suitable model to explain Japan's inflation dynamics. The second is that the NKPC does not fit well only because labor share is not a good proxy for RMC. In the following, we examine the latter possibility.

3.2 The NKPC with Labor Market Frictions

In Section 2.2, we have derived the representation of the NKPC in the presence of labor market frictions as (10). Since we regard that the series of employment DI (denoted as EDI_t) corresponds to the labor gap under sticky prices, we can introduce the following relationship:

$$LGAP_t^s = \delta EDI_t, \tag{19}$$

where δ is a scaling parameter.

As in the previous subsection, we apply the PVM for the estimation of the NKPC with labor market frictions. In doing so, we replace the matrix $\mathbf{Z}_t$ in (16) to include $\ln S_t$ as the first and EDI_t as the second variable. Then, the closed-form solution of (10) is represented as follows:

$$\begin{aligned} \pi_t &= b_0 + b_1 e_1'(\mathbf{I} - \beta\mathbf{A})^{-1}\mathbf{Z}_t + b_2\left[b_1 e_2'(\mathbf{I} - \beta\mathbf{A})^{-1}\mathbf{Z}_t + EDI_t - EDI_{t-1}\right] \\ &\quad + b_3 \sum_{h=0}^{\overline{h}} \rho^h \left[b_1 e_2'(\mathbf{I} - \beta\mathbf{A})^{-1}\mathbf{Z}_{t-h-1} + EDI_{t-h-1} - EDI_{t-h-2}\right], \end{aligned} \tag{20}$$

where $b_0 = \frac{1}{\gamma(1-\beta)} \ln \frac{\mu}{\alpha}$, $b_1 = \frac{1}{\gamma}$, $b_2 = \delta\left[(\alpha - 1) - (\alpha\sigma + \eta - 1)(1 - \rho)\right]$, and $b_3 = -\delta(\alpha\sigma + \eta - 1)(1 - \rho)\rho$, and e_2' is a vector with one in the second row and zeros elsewhere. Notice that this estimation form has a parameter restriction in a nonlinear way. Therefore, we must estimate it by nonlinear least squares (NLS). The combinations of endogenous variables in VAR are the same as in the previous subsection.

The sample period is 1977/Q3-2004/Q4.[16]

Table 2 shows the estimation results of (20). Compared to Table 1, we find that the fit of the NKPC is improved in every specification of VAR. The estimates of ρ are larger than 0.9, which implies that real wages are quite rigid in Japan. Interestingly, these values are almost the same as the autocorrelation coefficient of the U.S. economy's aggregate wage markup (the difference between real wage and MRS), which is estimated by Galí, Gertler, and López-Salido (2007) as 0.94 or 0.95. Therefore, the estimated ρ could be regarded as reasonable. Figure 3 shows that the consideration of real wage rigidity remarkably improves the performance of the NKPC.

Thus, the results in this section show that, if we correct labor share by incorporating two kinds of labor market frictions: (i) labor adjustment costs and (ii) real wage rigidity, the NKPC can explain Japan's inflation dynamics remarkably well.

3.3 The NKPC with Labor Market Frictions and Materials Prices

Here we estimate Japan's NKPC by additionally incorporating the influence of materials prices on RMC. As is shown in (13), the influence (ζ) depends on the value of the elasticity ε_m. To check the importance of ζ_t, we estimate the elasticity ε_m. Table 3 shows the estimation results for ε_m. Since ε_m is significantly larger than zero ($\varepsilon_m = 0.395$), the null hypothesis that the level of Q_t does not matter to m is rejected. Therefore, we must additionally include ζ_t in the calculation of RMC.

To apply the PVM, we replace the matrix $\mathbf{Z}_t$ to include $\ln(S_t + \zeta_t)$ as the first and EDI_t as the second variable. Then, the closed form of the NKPC with RMC is modified as follows:

$$
\begin{aligned}
\pi_t &= c_0 + c_1 e_1'(\mathbf{I} - \beta\mathbf{A})^{-1}\mathbf{Z}_t + c_2\left[c_1 e_2'(\mathbf{I} - \beta\mathbf{A})^{-1}\mathbf{Z}_t + EDI_t - EDI_{t-1}\right] \\
&\quad + c_3 \sum_{h=0}^{\overline{h}} \rho^h \left[c_1 e_2'(\mathbf{I} - \beta\mathbf{A})^{-1}\mathbf{Z}_{t-h-1} + EDI_{t-h-1} - EDI_{t-h-2}\right], \qquad (21)
\end{aligned}
$$

where $c_0 \simeq \frac{1}{\gamma(1-\beta)}\left(\ln\frac{\mu}{\alpha} + \ln\overline{\zeta}\right)$, $c_1 = \frac{1}{\gamma}$, $c_2 = \delta\left[(\alpha-1) - (\alpha\sigma + \eta - 1)(1-\rho)\right]$, and $c_3 = -\delta(\alpha\sigma + \eta - 1)(1-\rho)\rho$.[17]

The estimation results are presented in Table 4. The fit of the NKPC is further improved over Table 2 for every specification of VAR. Now we do not have noticeable serial correlation in the error term (see Figure 4 for the fit of the NKPC). Therefore, this result suggests that Japan's inflation dynamics are well explained within the framework of the NKPC, if we calculate RMC by incorporating labor market frictions and the influence of materials prices.

4 The Role of a "Backward-Looking" Component: Is It Really Necessary?

In this section, we examine the role of a backward-looking component in explaining Japan's inflation dynamics. The role of a backward-looking component has been stressed in many of the previous studies, such as Fuhrer and Moore (1995) and Fuhrer (1997). In the empirics of the NKPC, the earlier studies, such as Galí and Gertler (1999) and Galí, Gertler, and López-Salido (2001, 2005a), apply the generalized method of moments (GMM) for estimating the so-called "hybrid" NKPC, which includes a lagged inflation term as an additional explanatory variable, and report that the role of a backward-looking component is relatively minor. However, the more recent studies, such as Rudd and Whelan (2005 a,b,2006,2007), Lindé (2005), Roberts (2005), Jondeau and Le Bihan (2005), apply alternative empirical methodologies (the PVM or the maximum likelihood (ML)) for the estimation of the NKPC, and they report that a backward-looking component actually plays a more important role than considered in the earlier studies.[18]

Nevertheless, we can still consider the possibility that these studies overestimate the role of a backward-looking component due to the measurement problem of RMC, because most of the studies naively use labor share as the proxy for RMC. In this respect, our study has some potential to estimate more properly the role of a backward-looking component, because we calculate the measure of RMC by incorporating labor market frictions and the influence of materials prices, which have been neglected in most of the studies. To examine the role of a backward-looking component in Japan's inflation dynamics, we apply the approach of Rudd and Whelan (2005 a,b,2006,2007). Put concretely, we estimate the closed form solution of the NKPC ((18), (20), and (21)), by additionally including the lagged inflation term.

Table 5 shows the estimation results of the benchmark NKPC which includes the lagged inflation term. When we include lagged inflation term, *Adj*-R^2 ranges from 0.365 to 0.395. These are much higher than *Adj*-R^2 in the absence of lagged inflation term, which ranges from 0.103 to 0.209 (as in Table 1). The coefficient on lagged inflation term (around 0.5) also indicates the substantial role of lagged inflation for the fit of NKPC. In Figure 5, we observe that, by including the lagged inflation term, the fit of the benchmark NKPC is largely altered. These results indicate that, if we use labor share as the proxy for RMC, a backward-looking component plays an important role in the case of Japan. This is the same situation as in the U.S or the Euro area.

However, the results are dramatically altered by incorporating labor market frictions. Table 6 shows the estimation results of the NKPC with labor market frictions which includes the lagged inflation term. *Adj*-R^2 ranges from 0.384 to 0.424. These are not much higher than *Adj*-R^2 in the absence of lagged inflation term, which ranges from 0.319 to 0.391 (as in Table 2). Figure 6 also shows that the inclusion of lagged inflation term only slightly alters the fit of the NKPC. This indicates that the role of lagged inflation becomes less important if we correct labor share by incorporating labor market frictions.

Table 7 further shows the estimation results of the NKPC with labor market frictions and materials prices. *Adj*-R^2 ranges from 0.478 to 0.493. At this stage, these values are almost the same as *Adj*-R^2 in the absence of lagged inflation term, which ranges from 0.477 to 0.494 (as in Table 4). In addition, the coefficient of lagged inflation now becomes quite small (around 0.1) in every VAR specification. Figure 7 also shows that the inclusion of lagged inflation term has almost no influence on the fit of the NKPC. This result implies that lagged inflation is no more needed to explain Japan's inflation dynamics if we correct labor share by incorporating labor market frictions and materials prices.

In sum, the results in this section suggest that the role of backward-looking component can be overestimated due to the measurement problem of RMC. Actually, in the case of Japan, we find that the role of a backward-looking component completely disappears if we use the corrected measure of RMC. This implies that, at least in Japan, the observed role of a backward-looking component in the benchmark NKPC can be perfectly explained by the discrepancy between labor share and RMC. This is our most important finding.

5 Conclusions

In this study, we have estimated a New Keynesian Phillips curve (NKPC) in Japan, focusing on the measurement of real marginal cost (RMC). To obtain a better proxy for RMC, we have corrected labor share by taking account of two kinds of labor market frictions: (i) labor adjustment costs and (ii) real wage rigidity. Our results have shown that the consideration of these labor market frictions greatly improves the fit of Japan's NKPC. Furthermore, if we additionally incorporate materials prices in the calculation of RMC, then the fit of the NKPC is further improved. Our most important finding is that the conventional backward-looking component is no more needed to explain Japan's inflation dynamics if we use a corrected measure of RMC.

The evidence in Japan's economy provides some important implications for the literature. First, our results suggest that obtaining a good proxy for RMC is crucial for evaluating the performance of the NKPC. This implies that, at least in Japan, the argument of Rotemberg and Woodford (1999) is relevant for evaluating the performance of the NKPC, as predicted by Wolman (1999). As our study shows, poor proxies of RMC typically lead us to underestimate the fit of the NKPC and to overstate the importance of lagged inflation. Although the existing studies conventionally use labor share as the proxy for RMC, more serious efforts to find a better proxy for RMC could contribute to the better understanding about the performance of the NKPC.

Second, our results indicate that labor market frictions are the key elements to explain the movements of RMC. This finding is consistent with some recent analysis on the causes of aggregate economic inefficiency. Galí, Gertler, and López-Salido (2007) find that the "wage markup", defined as the deviation of MRS from real wage, explains most of the costs of the U.S. business cycles. Chari, Kehoe, and McGrattan

(2007) show that the "labor wedge", which is defined as the deviation of the marginal product of labor from MRS, is the most essential element for the U.S. aggregate economic inefficiency within their framework of business cycle accounting. Based on the same framework, Kobayashi and Inaba (2006) show that the large and persistent movements of the labor wedge may have been a major contributor to Japan's decade-long recession in the 1990s. Although our empirical viewpoint is different from these studies, our evidence also support the idea that labor market frictions are critical factors to understand macroeconomic dynamics.

Appendix A: Relationship between Labor Adjustment Costs and the Labor Gap

In this appendix, we derive the relationship between the sum of discounted marginal labor adjustment costs and the labor gap under sticky prices. To do so, we take the following steps. First, we derive the relationship between the sum of discounted marginal labor adjustment costs and the labor gap under flexible prices. Second, we derive the relationship between the labor gap under flexible prices and the labor gap under sticky prices. Finally, we combine these two relationships.

Here we derive the relationship between the sum of discounted marginal labor adjustment costs and the labor gap under flexible prices.

Under the flexible price economy, the optimality condition for the firm is (2). When labor adjustment costs are relevant, real marginal cost is given by (7). From (2), (4) and (7), we have the following expression of optimal price under flexible prices (in logarithm):

$$\ln P_t^* = \ln \frac{\theta W_t A_t^{-1} L_t^{*1-\alpha}}{\alpha(\theta-1)} + \ln \left[1 + \frac{1}{W_t} E_t \sum_{k=0}^{\infty} \beta^k \left(\frac{\partial \Omega_{t+k}}{\partial L_t} \mid_{L_{t+k}=L_{t+k}^* \ \forall\ k} \right) \right]. \tag{A1}$$

Next, by combining (4) and (8), we have another expression of $\ln P_t^*$:

$$\ln P_t^* = \ln W_t - \frac{1-\rho}{1-\rho B} \ln A_t^{\sigma} L_t^{*\alpha\sigma+\eta-1}. \tag{A2}$$

From (A1) and (A2), we obtain the following condition:

$$\ln \frac{\theta A_t^{-1} L_t^{*1-\alpha}}{\alpha(\theta-1)} + \ln \left[1 + \frac{1}{W_t} E_t \sum_{k=0}^{\infty} \beta^k \left(\frac{\partial \Omega_{t+k}}{\partial L_t} \mid_{L_{t+k}=L_{t+k}^* \ \forall\ k} \right) \right]$$

$$= -\frac{1-\rho}{1-\rho B} \ln A_t^{\sigma} L_t^{*\alpha\sigma+\eta-1}. \tag{A3}$$

The condition (A3) holds in the presence of labor adjustment costs. The corresponding condition in the absence of labor adjustment costs is given by:

$$\ln \frac{\theta A_t^{-1} \overline{L}_t^{*1-\alpha}}{\alpha(\theta-1)} = -\frac{1-\rho}{1-\rho B} \ln A_t^{\sigma} \overline{L}_t^{*\alpha\sigma+\eta-1}. \tag{A4}$$

Then, from (A3) and (A4), we can derive the relationship between the sum of discounted marginal labor adjustment costs and the labor gap under flexible prices, which is defines as $LGAP_t^* \equiv \ln L_t^* - \ln \overline{L}_t^*$, as follows:

$$\begin{aligned} & \ln\left[1 + \frac{1}{W_t} E_t \sum_{k=0}^{\infty} \beta^k \left(\frac{\partial \Omega_{t+k}}{\partial L_t} \mid_{L_{t+k}=L_{t+k}^* \ \forall \ k} \right)\right] \\ = & \left[\alpha - 1 - \frac{(\alpha\sigma+\eta-1)(1-\rho)}{1-\rho B}\right] LGAP_t^*. \end{aligned} \tag{A5}$$

As the second step, we derive the relationship between the labor gap under flexible prices and the labor gap under sticky prices. From (4) and (8), we obtain

$$\ln P_t = \ln W_t - \frac{1-\rho}{1-\rho B} \ln A_t^{\sigma} L_t^{\alpha\sigma+\eta-1}. \tag{A6}$$

Firm's optimality condition under price adjustment cost function (1) is given by:

$$\ln \frac{P_t^s}{P_{t-1}^s} = \beta E_t \ln \frac{P_{t+1}^s}{P_t^s} + \frac{1}{\gamma} \ln \frac{P_t^*}{P_t^s}. \tag{A7}$$

By substituting (A6) and (A7), we can derive the following condition:

$$\ln \frac{L_t^s}{L_{t-1}^s} = \beta E_t \ln \frac{L_{t+1}^s}{L_t^s} + \frac{1}{\gamma} \ln \frac{L_t^*}{L_t^s} + \Gamma_t, \tag{A8}$$

where L_t^s is the optimal number of workers under sticky prices in the presence of labor adjustment costs, and Γ_t represents the purely exogenous factor. Similarly, we can derive the condition about the optimal number of workers under sticky prices in the absence of labor adjustment costs ($\overline{L}_t^s$) as follows:

$$\ln \frac{\overline{L}_t^s}{\overline{L}_{t-1}^s} = \beta E_t \ln \frac{\overline{L}_{t+1}^s}{\overline{L}_t^s} + \frac{1}{\gamma} \ln \frac{\overline{L}_t^*}{\overline{L}_t^s} + \Gamma_t. \tag{A9}$$

Define the labor gap under sticky prices as $LGAP_t^s \equiv \ln L_t^s - \ln \overline{L}_t^s$. Then, from (A8) and (A9), the relationship between $LGAP_t^*$ and $LGAP_t^s$ is derived as follows:

$$LGAP_t^* = (1 + \gamma + \gamma\beta) LGAP_t^s - \gamma LGAP_{t-1}^s - \gamma\beta E_t LGAP_{t+1}^s. \tag{A10}$$

Finally, by substituting (A10) into (A5), we obtain the relationship between the sum of discounted marginal labor adjustment costs and the labor gap under sticky prices as follows:

$$\begin{aligned} & \ln\left[1 + \frac{1}{W_t} E_t \sum_{k=0}^{\infty} \beta^k \left(\frac{\partial \Omega_{t+k}}{\partial L_t} \,|_{L_{t+k}=L_{t+k}^* \ \forall\ k} \right)\right] \\ = \ & \left[\alpha - 1 - \frac{(\alpha\sigma + \eta - 1)(1-\rho)}{1-\rho B}\right] \\ & \left[(1 + \gamma + \gamma\beta) LGAP_t^s - \gamma LGAP_{t-1}^s - \gamma\beta E_t LGAP_{t+1}^s\right]. \end{aligned} \tag{A11}$$

Appendix B: Data Description

As for the inflation rate, we use the seasonally adjusted GDP deflator (quarter-to-quarter). As for labor share, we cannot use the conventional definition, which is the System of National Accounts' (SNA's) "compensation of employees" divided by "national income," because the definition of "compensation of employees" does not include the compensation of the self-employed firms. For this reason, we use the following definition recommended by Batini, Jackson, and Nickell (2000), Kamada and Masuda (2001):

$$\text{labor share} = \frac{\text{compensation of employees}}{\text{nominal GDP}-(\text{indirect tax}-\text{subsidy})-\text{households' operating surplus}}.$$

This definition assumes that labor share in the self-employed firms is just the same as that in other firms.

As for the material inputs and materials prices, we cannot obtain the quarterly series from SNA. So, we construct a quarterly series of material inputs and the materials prices, following the interpolation method of Chow and Lin (1971). To estimate the quarterly series of materials prices, we use the price of intermediate materials in the Corporate Goods Price Index (CGPI) published by the Bank of Japan. To estimate the quarterly series of the quantity of nominal material inputs ($P_{M,t}M_t$), we use the series of the Financial Statements Statistics of Corporations published by the Ministry of Finance. The definition is sales subtracted by operating profits, personnel expenses, and depreciation.

Appendix C: The NKPC with Labor Market Frictions: The case of Staggered Real Wage Setting

We check the robustness of our results by using a micro-founded model of real wage rigidity, which is derived in Appendix B of Blanchard and Galí (2007). The model is given as follows:

$$\ln \frac{W_t}{P_t} = \Phi \ln \frac{W_{t-1}}{P_{t-1}} + \Phi\beta E_t \ln \frac{W_{t+1}}{P_{t+1}} + \Lambda \ln Y_t^{\sigma} L_t^{\eta-1}. \tag{C1}$$

Thus, this model differs from (8) in that it includes forward-looking expectation ($E_t\omega_{t+1}$). Using backshift operator (B), (C1) can be rewritten as follows:

$$\ln \frac{W_t}{P_t} = (1-\xi\beta B^{-1})^{-1}(1-\xi B)^{-1}(\xi/\Phi)\Lambda \ln Y_t^{\sigma} L_t^{\eta-1}, \tag{C2}$$

where $\xi = \frac{1+\sqrt{1-4\Phi^2\beta}}{2\Phi\beta}$.

Next, we calculate RMC. Using (2), (4), (7), (A7), and (C2), we obtain the following relationship between the marginal labor adjustment costs and labor gap under flexible prices:

$$\begin{aligned} & \ln\left[1+\frac{1}{W_t}E_t\sum_{k=0}^{\infty}\beta^k\left(\frac{\partial\Omega_{t+k}}{\partial L_t}\ |_{L_{t+k}=L^*_{t+k}\ \forall\ k}\right)\right] \\ = & \left[(\alpha-1)-(1-\xi\beta B^{-1})^{-1}(1-\xi B)^{-1}\frac{\xi\Lambda}{\Phi}(\alpha\sigma+\eta-1)\right]LGAP_t^*. \end{aligned} \tag{C3}$$

Then we obtain the following expression of RMC:

$$\begin{aligned} \ln RMC_t \ = \ & \ln\frac{1}{\alpha} + \ln S_t + \left[(\alpha-1)-(1-\xi\beta B^{-1})^{-1}(1-\xi B)^{-1}\frac{\xi\Lambda}{\Phi}(\alpha\sigma+\eta-1)\right] \\ & \left[(1+\gamma+\gamma\beta)LGAP_t^s - \gamma LGAP_{t-1}^s - \gamma\beta E_t LGAP_{t+1}^s\right]. \end{aligned} \tag{C4}$$

By substituting (C4) into (3), we derive the NKPC as follows:

$$\begin{aligned}
\pi_t &= \beta E_t \pi_{t+1} + \frac{1}{\gamma} \ln \frac{\mu}{\alpha} + \frac{1}{\gamma} \ln S_t \\
&\quad + \frac{1}{\gamma} \left[(\alpha - 1) - (1 - \xi\beta B^{-1})^{-1} (1 - \xi B)^{-1} \frac{\xi\Lambda}{\Phi} (\alpha\sigma + \eta - 1) \right] \\
&\quad \left[(1 + \gamma + \gamma\beta) LGAP_t^s - \gamma LGAP_{t-1}^s - \gamma\beta E_t LGAP_{t+1}^s \right]. \qquad \text{(C5)}
\end{aligned}$$

Using the VAR model that is introduced in Sections 3.2, we can express the closed-form solution of (C5) as follows:

$$\begin{aligned}
\pi_t &= d_0 + d_1 e_1' (\mathbf{I} - \beta \mathbf{A})^{-1} \mathbf{Z}_t + d_2 \left[d_1 e_2' (\mathbf{I} - \beta \mathbf{A})^{-1} \mathbf{Z}_t + EDI_t - EDI_{t-1} \right] \\
&\quad + d_3 \sum_{h=1}^{\infty} \xi^h \left[d_1 e_2' (\mathbf{I} - \beta \mathbf{A})^{-1} \mathbf{Z}_{t-h} + (EDI_{t-h} - EDI_{t-h-1}) \right] \\
&\quad + d_3 \sum_{j=1}^{\infty} (\xi\beta)^j e_2' \left[d_1 \left((\mathbf{I} - \beta \mathbf{A})^{-1} - \sum_{l=1}^{j} \mathbf{A}^l \right) + (\mathbf{A}^j - \mathbf{A}^{j-1}) \right] \mathbf{Z}_t, \qquad \text{(C6)}
\end{aligned}$$

where $d_0 = \frac{1}{\gamma(1-\beta)} \ln \frac{\mu}{\alpha}$, $d_1 = \frac{1}{\gamma}$, $d_2 = \delta \left[(\alpha - 1) - \frac{\xi}{\Phi} \Lambda \frac{(\alpha\sigma+\eta-1)}{1-\xi^2\beta} \right]$, $d_3 = -\frac{\xi}{\Phi} \Lambda \frac{(\alpha\sigma+\eta-1)\delta}{1-\xi^2\beta}$.

The estimation results of (C6) are presented in the Appendix Table. The estimated ξ is quite high in every specification of auxiliary VAR. Therefore, the results indicate that real wage rigidity is important in the calculation of RMC. The fit of the NKPC is shown in the Appendix Figure. By incorporating real wage rigidity, the fit of the NKPC is remarkably improved. This result is essentially the same as the result in Section 3.2.

Notes

[1]As for the Euro area, Bardsen, Jansen, and Nymoen (2004) show that the favorable evidence for the NKPC reported by Galí, Gertler, and López-Salido (2001) depend on specific choices made about estimation methodology. Based on the extended empirical framework (variable addition and encompassing of existing models), they report that the forward-looking aspect is not relevant for the inflation dynamics in the Euro area. However, they still use labor share as the proxy for RMC.

[2]Rudd and Whelan (2005) acknowledge the possibility that the poor performance of the NKPC comes from the discrepancy between labor share and RMC. They describe that "on balance, then, we conclude that it remains possible that some forward-looking model based on a measure of real marginal cost provides a good description of the inflation process, but this conjecture can by no means be considered proven" (p. 311).

[3]Leith and Malley [2007] report that the parameters of the NKPC for the U.S. economy (both in industry-level and aggregate level) are reasonably estimated if the cost of materials, rather than labor share, is used as the proxy for RMC. Our approach is different from theirs because we partially correct labor share by incorporating labor market frictions and the influence of materials prices, rather than perfectly replacing labor share by the costs of materials. However, Leith and Malley [2007] and our study share the idea that obtaining a better proxy for RMC than labor share is crucial for evaluating the performance of the NKPC.

[4]In this study, we do not investigate the mechanism of variations of the desired markup, since this issue is still controversial and it is not clear to which model we should particularly pay attention (see the conclusions of Rotemberg and Woodford (1999)).

[5]We assume that labor is the only variable production input. Therefore, other

inputs, such as capital stock, are assumed to be exogenous and are included in the calculation of A_t.

[6]As for labor adjustment cost function, some previous studies (such as Batini, Jacksosn, and Nickell (2005)) have specifically focused on the symmetric quadratic form. However, we do not specify the exact form of labor adjustment cost function. The reason is twofold. First, the argument on whether such a symmetric quadratic form can approximate the aggregate labor adjustment cost function is still highly controversial in the literature of labor adjustment costs (Caballero and Engel (2004), Cooper and Willis (2002, 2004a,b)). Second, especially in the case of Japan, it seems plausible that the form of labor adjustment cost function is more complex than the U.S. because of the presence of a long-term employment relationship, as indicated in many studies (for example, Hashimoto and Raisian (1985)). The virtue of our approach is to avoid specifying the exact form of labor adjustment cost function.

[7]The reason why Ω_t depends on the labor prior to time $t-1$ $(L_{t-2}, L_{t-3}, \cdots)$ is explained by the possibility that firms might have to incur the cost of adjusting labor input more than one period.

[8]The *TANKAN* survey is the broadest survey of the conditions of Japanese enterprises. As of March 2006, it covers 10,087 firms (4,156 manufacturing firms and 5,931 non-manufacturing firms).

[9]We assume that real wage rigidity arises solely due to the problems of the household sector. This implies that firms are wage takers.

[10]The backward shift operator is the function that translates $BE_t x_{t+1}$ into $E_{t-1}x_t$. This operator is more convenient in our analysis than the lag operator (L), which translates $LE_t x_{t+1}$ into x_t.

[11]This corresponds to the situation where the firm has different kinds of labor inputs that vary in terms of the efficiency of the use of materials, and puts a high

priority on the use of efficient labor. As a result, in the production margin, the firm must use relatively inefficient labor inputs which require many material inputs to produce one additional unit of gross output.

[12]The PVM was used originally by Campbell and Shiller (1987) in the context of stock price determination.

[13]Since we assume that (16) is the true data generating process of labor share, we may ignore the endogeneity problem in estimating (18).

[14]Woodford (2001) reports that, if the VAR includes labor share and the growth of unit labor cost, the fit of the NKPC is fairly good in the U.S. Rudd and Whelan (2005a) show that including the inflation rate in VAR largely alters the fit of NKPC in the U.S.

[15]As Kurmann (2005) point out, standard errors on the estimated coefficients will be underestimated, because we neglect the standard errors in the auxiliary VAR. So, our argument focuses on the fit of the NKPC in the point estimates (expressed as $Adj\text{-}R^2$).

[16]The sample period is shorter than the previous subsection because we must truncate the sample if we specify the value of $\overline{h}$ as more than 1. Theoretically, $\overline{h}$ should be infinity. However, the choice of a large value of $\overline{h}$ reduces the degree of freedom. So we choose $\overline{h} = 10$. But we have confirmed that the results do not change much as long as we select a sufficiently large $\overline{h}$.

[17]$\overline{\zeta}$ denotes the steady-state value of ζ_t.

[18]Mavroeidis (2005) show that the problem of weak identification cannot be ruled out in estimating the NKPC with GMM. He demonstrated that when the model is weakly identified, the GMM estimation will be biased in favor of hybrid NKPC with apparently dominant forward-looking behavior, irrespective of the true nature of the forward and backward-looking dynamics of inflation. Rudd and Whelan (2005b) raise

similar issues.

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References

[1] Bardsen, Gunnar, Eilev Jansen, and Ragnar Nymoen, "Econometric Evaluation of the New Keynesian Phillips Curve," *Oxford Bulletin of Economics and Statistics*, 66:s1 (2004), 671-686.

[2] Batini, Nicoletta, Brian Jackson, and Stephen Nickell, "Inflation Dynamics and the Labour Share in the UK," *Bank of England External MPC Unit Discussion Paper*, 2 (2000).

[3] Batini, Nicoletta, Brian Jackson, and Stephen Nickell, "An Open-Economy New Keynesian Phillips Curve for the U.K." *Journal of Monetary Economics*, 52:6 (2005), 1061-1071.

[4] Bils, Mark, "The Cyclical Behavior of Marginal Cost and Price" *American Economic Review*, 77:5 (1987), 838-855.

[5] Bils, Mark and James Kahn, "What Inventory Behavior Tells Us about Business Cycles" *American Economic Review*, 90:3 (2000), 458-481.

[6] Blanchard, Oliver and Jordi Galí, "Real Wage Rigidities and the New Keynesian Model," *Journal of Money, Credit, and Banking*, 39:s1 (2007), 35-65.

[7] Caballero, Ricardo and Eduardo Engel, "A Comment on the Economics of Labor Adjustment: Mind the Gap: Reply," *American Economic Review*, 94:4 (2004), 1238-1244.

[8] Calvo, Gulliermo, "Staggered Prices in a Utility Maximizing Framework," *Journal of Monetary Economics*, 12:3 (1983), 383-398.

[9] Campbell, John and Robert Shiller, "Cointegration and Tests of Present Value Models," *Journal of Political Economy*, 95:5 (1987), 1062-1088.

[10] Chari, V, Patrick Kehoe, and Ellen McGrattan, "Business Cycle Accounting," *Econometrica*, 75:3 (2007), 781-836.

[11] Chow, Gregory and An-loh Lin, "Best Linear Unbiased Interpolation, Distribution, and Extrapolation of Time Series by Related Series," *The Review of Economics and Statistics*, 53:4 (1971), 372-375.

[12] Cooper, Russell and Jonathan Willis, "The Cost of Labor Adjustment: Inference from the Gap," *Federal Reserve Bank of Kansas City Research Working Paper* 02:11 (2002).

[13] Cooper, Russell and Jonathan Willis, "A Comment on the Economics of labor Adjustment: Mind the Gap," American Economic Review, 94:4 (2004a), 1223-1237

[14] Cooper, Russell and Jonathan Willis, “A Comment on the Economics of labor Adjustment: Mind the Gap: Rejoinder,” *American Economic Review*, 94:4 (2004b), 1245-1247.

[15] Fuhrer, Jeffrey, “The (Un)importance of Forward-Looking Behavior in Price Specifications,” *Journal of Money, Credit, and Banking*, 29:3 (1997), 338-350.

[16] Fuhrer, Jeffrey and George Moore, “Inflation Persistence,” *Quarterly Journal of Economics*, 110:1 (1995), 127-159.

[17] Galí, Jordi and Mark Gertler, “Inflation Dynamics: A Structural Econometric Approach,” *Journal of Monetary Economics*, 44:2 (1999), 195-222.

[18] Galí, Jordi and Mark Gertler, and David López-Salido, “European Inflation Dynamics,” *European Economic Review*, 45:7 (2001), 1237-1270.

[19] Galí, Jordi and Mark Gertler, and David López-Salido, “Markups, Gaps, and the Welfare Costs of Business Fluctuations,” *The Review of Economics and Statistics*, 89:1 (2007), 44-59.

[20] Hashimoto, Masanori and John Raisian, “Employment Tenure and Earnings Profiles in Japan and the United States,” *American Economic Review*, 75:4 (1985), 721-735.

[21] Jondeau, Eric and Hervé Le Bihan, “Testing for the New Keynesian Phillips Curve. Additional International Evidence,” *Economic Modelling*, 22:3 (2005), 521-550.

[22] Kamada, Koichiro and Kazuto Masuda, “Effects of Measurement Error on the Output Gap in Japan,” *Monetary and Economic Studies*, 19:2 (2001), 109-154.

[23] Kobayashi, Keiichiro and Masaru Inaba, “Business Cycle Accounting for the Japanese Economy,” *Japan and the World Economy*, 18:4 (2006), 418-440.

[24] Kurmann, Andre, “Quantifying the Uncertainty about the Fit of a New Keynesian Pricing Model,” *Journal of Monetary Economics*, 52:6 (2005), 1119-1134.

[25] Leith, Campbell and Jim Malley, “A Sectoral Analysis of Price-Setting Behavior in U.S. Manufacturing Industries,” *The Review of Economics and Statistics*, 89:2 (2007), 335-342.

[26] Lindé, Jesper, “Estimating New-Keynesian Phillips Curves: A Full Information Maximum Likelihood Approach,” *Journal of Monetary Economics*, 52:6 (2005), 1135-1149.

[27] Mavroeidis, Sophocles, “Identification Issues in Forward-Looking Models Estimated by GMM, with an Application to the Phillips Curve,” *Journal of Money, Credit, and Banking*, 37:3 (2005), 421-448.

[28] Roberts, John, "How Well Does the New Keynesian Sticky-Price Model Fit the Data?" *The B.E. Journal of Macroeconomics*, Contributions to Macroeconomics, 5:10 (2005), 1-37.

[29] Rotemberg, Julio, "Sticky Prices in the United States," *Journal of Political Economy*, 90:6 (1982a), 1187-1211.

[30] Rotemberg, Julio, "Monopolistic Price Adjustment and Aggregate Output," *Review of Economic Studies*, 49:4 (1982b), 517-531.

[31] Rotemberg, Julio and Michael Woodford, "The Cyclical Behavior of Prices and Costs," in J. Taylor and M. Woodford (Eds.), *Handbook of Macroeconomics*, Vol. 1B (Amsterdam: North-Holland, 1999).

[32] Rudd, Jeremy, and K. Whelan, "Does Labor's Share Drive Inflation?" *Journal of Money, Credit, and Banking*, 37:2 (2005a), 297-312.

[33] Rudd, Jeremy, and K. Whelan, "New Tests of the New-Keynesian Phillips Curve," *Journal of Monetary Economics*, 52:6 (2005b), 1167-1181.

[34] Rudd, Jeremy, and K. Whelan, "Modelling Inflation Dynamics: A Critical Review of Recent Research," *Journal of Money, Credit, and Banking*, 39:s1 (2007), 155-170.

[35] Rudd, Jeremy, and K. Whelan, "Can Rational Expectations Sticky-Price Models Explain Inflation Dynamics?" *American Economic Review*, 96:1 (2006), 303-320.

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

[37] Wolman, Alexander, "Sticky Prices, Marginal Cost, and the Behavior of Inflation," *Federal Reserve Bank of Richmond, Economic Quarterly*, 85:4 (1999), 29-48.

[38] Woodford, Michael, "The Taylor Rule and Optimal Monetary Policy," *American Economic Review*, 91:2 (2001), 232-237.

TABLE 1: Benchmark NKPC

	VAR specifications		
	$\begin{pmatrix} lnS_t \end{pmatrix}$	$\begin{pmatrix} lnS_t \\ \Delta ULC_t \end{pmatrix}$	$\begin{pmatrix} lnS_t \\ \pi_t \end{pmatrix}$
a_0	0.186	0.317	0.240
t-value	(4.42)	(3.87)	(5.79)
a_1	0.004	0.008	0.006
t-value	(4.33)	(3.82)	(5.70)
$Adj\text{-}R^2$	0.130	0.103	0.209
D.W.	*0.823*	*0.828*	*0.861*
VAR lags	2	1	2

Note: The dependent variable is the GDP deflator (non-annualized). The estimation method is OLS. The sample period is 1975/Q1-2004/Q4. VAR lags are chosen by Schwarz's information criterion.

TABLE 2: NKPC with Labor Market Frictions

	VAR specifications		
	$\begin{pmatrix} lnS_t \\ EDI_t \end{pmatrix}$	$\begin{pmatrix} lnS_t \\ EDI_t \\ \Delta ULC_t \end{pmatrix}$	$\begin{pmatrix} lnS_t \\ EDI_t \\ \pi_t \end{pmatrix}$
b_0	0.382	0.373	0.456
t-value	(5.83)	(5.71)	(6.87)
b_1	0.009	0.009	0.011
t-value	(5.78)	(5.66)	(6.82)
b_2	-0.008	-0.008	-0.014
t-value	(-0.52)	(-0.57)	(-0.99)
b_3	-0.016	-0.016	-0.017
t-value	(-2.58)	(-2.56)	(-2.98)
ρ	0.939	0.941	0.940
t-value	(11.83)	(11.78)	(13.75)
$Adj\text{-}R^2$	0.328	0.319	0.391
D.W.	1.492	1.480	1.547
VAR lags	2	2	2

Note: The dependent variable is the GDP deflator (non-annualized). The estimation method is NLS. The sample period is 1977/Q3-2004/Q4. VAR lags are chosen by Schwarz's information criterion.

TABLE 3: Elasticity of Materials/Output Ratio to the Level of Output

ε_m	0.395
t-value	(6.36)
const	-0.008
t-value	(-2.91)
trend	0.000
t-value	(1.95)
R^2	0.257
D.W.	2.311

Note: The dependent variable is ln(M_t/Q_t)-ln(M_{t-1}/Q_{t-1}). The explanatory variables are ln(Q_t)-ln(Q_{t-1}), constant, and time-trend. The estimation method is OLS. The sample period is 1975/Q1-2004/Q4.

TABLE 4: NKPC with Labor Market Frictions and Materials Prices

	VAR specifications		
	$\begin{pmatrix} ln(S_t+\zeta_t) \\ EDI_t \end{pmatrix}$	$\begin{pmatrix} ln(S_t+\zeta_t) \\ EDI_t \\ \Delta ULC_t \end{pmatrix}$	$\begin{pmatrix} ln(S_t+\zeta_t) \\ EDI_t \\ \pi_t \end{pmatrix}$
c_0	0.084	0.081	0.086
t-value	(9.28)	(9.04)	(9.33)
c_1	0.003	0.003	0.004
t-value	(8.97)	(8.72)	(9.02)
c_2	0.008	0.008	0.007
t-value	(0.60)	(0.56)	(0.55)
c_3	-0.013	-0.013	-0.013
t-value	(-2.44)	(-2.44)	(-2.46)
ρ	0.958	0.961	0.961
t-value	(11.54)	(11.62)	(11.72)
Adj-R^2	0.490	0.477	0.494
D.W.	*1.870*	*1.835*	*1.857*
VAR lags	2	2	2

Note: The dependent variable is the GDP deflator (non-annualized). The estimation method is NLS. The sample period is 1977/Q3-2004/Q4. VAR lags are chosen by Schwarz's information criterion.

TABLE 5: Benchmark NKPC with Inflation Lag

	VAR specifications		
	$\begin{pmatrix} lnS_t \end{pmatrix}$	$\begin{pmatrix} lnS_t \\ \Delta ULC_t \end{pmatrix}$	$\begin{pmatrix} lnS_t \\ \pi_t \end{pmatrix}$
a_0	0.082	0.129	0.124
t-value	(2.12)	(1.75)	(3.02)
a_1	0.002	0.003	0.003
t-value	(2.09)	(1.73)	(2.98)
inflation lag	0.506	0.520	0.461
t-value	(6.82)	(7.06)	(6.10)
Adj-R²	0.372	0.365	0.395
D.W.	*2.128*	*2.155*	*2.057*
VAR lags	2	1	2

Note: The dependent variable is the GDP deflator (non-annualized). The estimation method is OLS. The sample period is 1975/Q1-2004/Q4. VAR lags are chosen by Schwarz's information criterion.

TABLE 6: NKPC with Labor Market Frictions and Inflation Lag

	VAR specifications		
	$\begin{pmatrix} lnS_t \\ EDI_t \end{pmatrix}$	$\begin{pmatrix} lnS_t \\ EDI_t \\ \Delta ULC_t \end{pmatrix}$	$\begin{pmatrix} lnS_t \\ EDI_t \\ \pi_t \end{pmatrix}$
b_0	0.251	0.241	0.332
t-value	(3.67)	(3.56)	(4.53)
b_1	0.006	0.006	0.008
t-value	(3.64)	(3.53)	(4.50)
b_2	0.001	0.001	-0.005
t-value	(0.10)	(0.09)	(-0.35)
b_3	-0.014	-0.014	-0.016
t-value	(-2.21)	(-2.18)	(-2.61)
ρ	0.908	0.908	0.923
t-value	(9.23)	(9.13)	(11.49)
inflation lag	0.305	0.313	0.241
t-value	(3.41)	(3.50)	(2.73)
Adj-R²	0.389	0.384	0.424
D.W.	2.257	2.260	2.143
VAR lags	2	2	2

Note: The dependent variable is the GDP deflator (non-annualized). The estimation method is NLS. The sample period is 1977/Q3-2004/Q4. VAR lags are chosen by Schwarz's information criterion.

TABLE 7: NKPC with Labor Market Frictions, Materials Prices, and Inflation Lag

	VAR specifications		
	$\begin{pmatrix} ln(S_t+\zeta_t) \\ EDI_t \end{pmatrix}$	$\begin{pmatrix} ln(S_t+\zeta_t) \\ EDI_t \\ \Delta ULC_t \end{pmatrix}$	$\begin{pmatrix} ln(S_t+\zeta_t) \\ EDI_t \\ \pi_t \end{pmatrix}$
c_0	0.076	0.071	0.078
t-value	(6.14)	(5.91)	(6.20)
c_1	0.003	0.003	0.003
t-value	(6.01)	(5.78)	(6.07)
c_2	0.009	0.009	0.009
t-value	(0.69)	(0.68)	(0.64)
c_3	-0.013	-0.013	-0.013
t-value	(-2.29)	(-2.26)	(-2.31)
ρ	0.944	0.944	0.948
t-value	(10.36)	(10.21)	(10.54)
inflation lag	0.088	0.108	0.087
t-value	(0.92)	(1.13)	(0.92)
Adj-R^2	0.489	0.478	0.493
D.W.	*2.070*	*2.081*	*2.057*
VAR lags	2	2	2

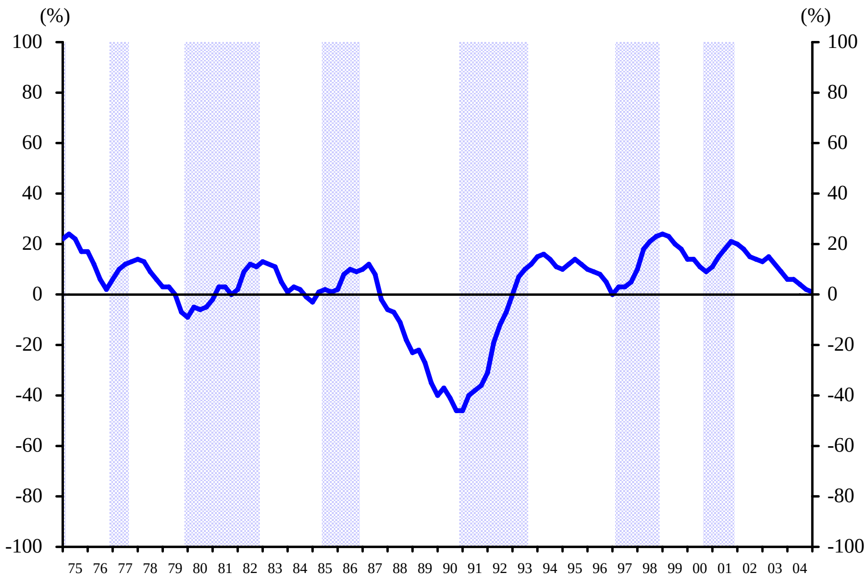
Note: The dependent variable is the GDP deflator (non-annualized). The estimation method is NLS. The sample period is 1977/Q3-2004/Q4. VAR lags are chosen by Schwarz's information criterion.

APPENDIX TABLE: NKPC with Labor Market Frictions
(With Model of Staggered Real Wage Setting)

	VAR specifications		
	$\begin{pmatrix} lnS_t \\ EDI_t \end{pmatrix}$	$\begin{pmatrix} lnS_t \\ EDI_t \\ \Delta ULC_t \end{pmatrix}$	$\begin{pmatrix} lnS_t \\ EDI_t \\ \pi_t \end{pmatrix}$
d_0	0.664	0.669	0.860
t-value	(7.53)	(7.84)	(10.22)
d_1	0.016	0.016	0.020
t-value	(7.48)	(7.79)	(10.17)
d_2	0.000	0.006	0.012
t-value	(-0.02)	(0.32)	(0.72)
d_3	-0.018	-0.021	-0.026
t-value	(-2.83)	(-3.15)	(-4.35)
ξ	0.909	0.878	0.851
t-value	(12.48)	(12.77)	(16.59)
Adj-R^2	0.287	0.302	0.427
D.W.	1.463	1.487	1.534
VAR lags	2	2	2

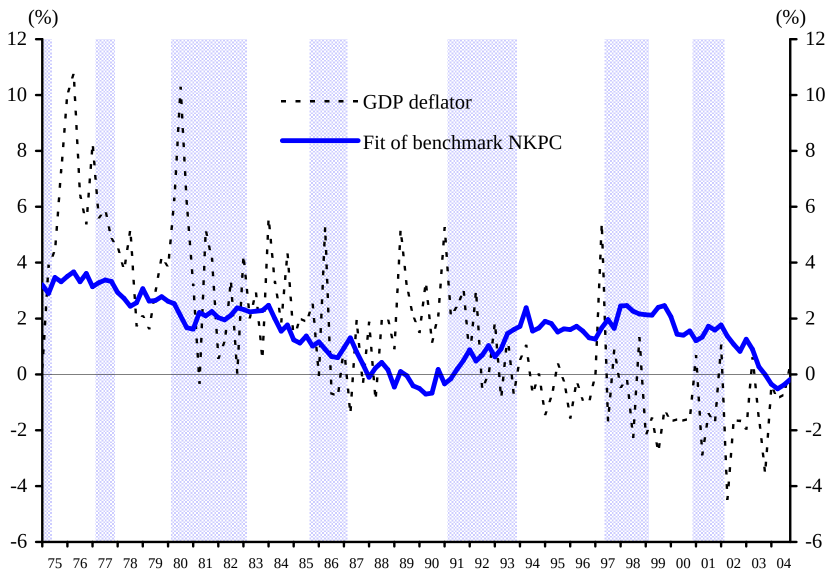
Note: The dependent variable is the GDP deflator (non-annualized). The estimation method is NLS. The sample period is 1977/Q3-2004/Q4. VAR lags are chosen by Schwarz's information criterion.

FIGURE 1: Labor Gap in Japan



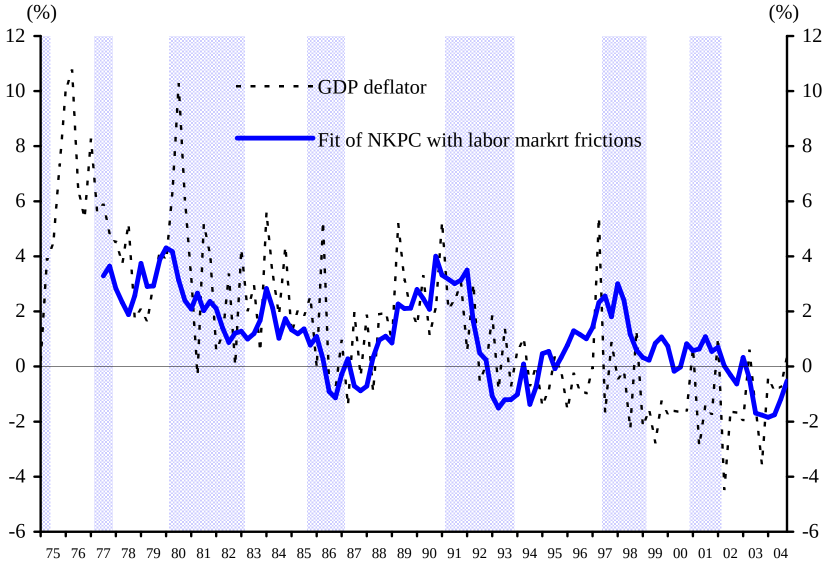
Note: The figure shows the employment DI in the Bank of Japan's *Tankan* survey.
Shaded areas indicate recession dates.

FIGURE 2: Benchmark NKPC



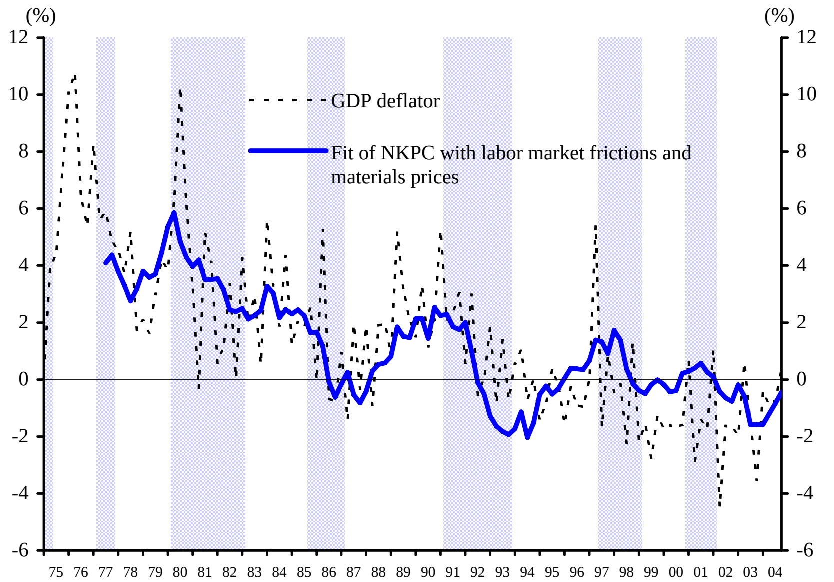
Note: The NKPC is based on the auxiliary VAR that includes only lnS_t.

FIGURE 3: NKPC with Labor Maket Frictions



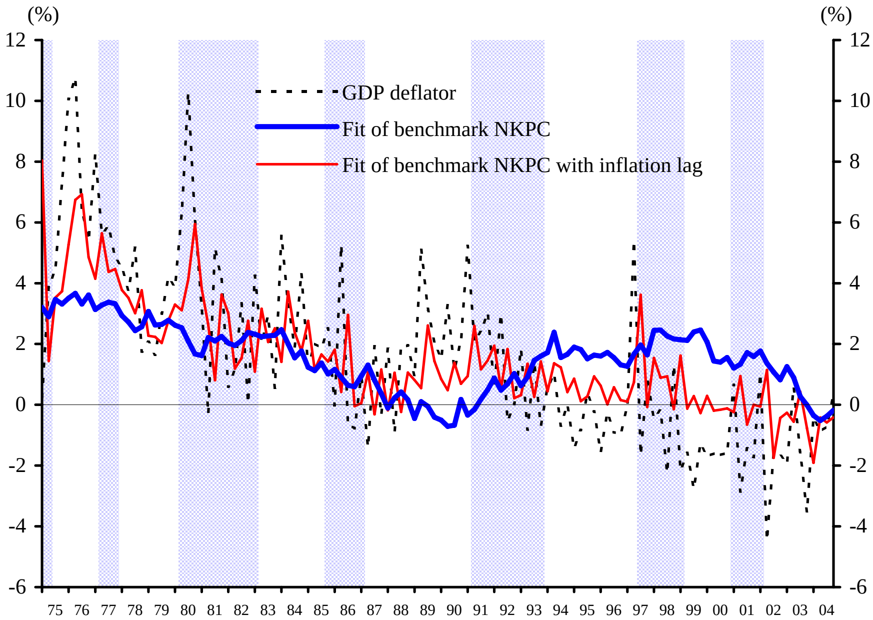
Note: The NKPC is based on the auxiliary VAR that includes lnS_t and EDI_t.

FIGURE 4: NKPC with Labor Market Frictions and Materials Prices



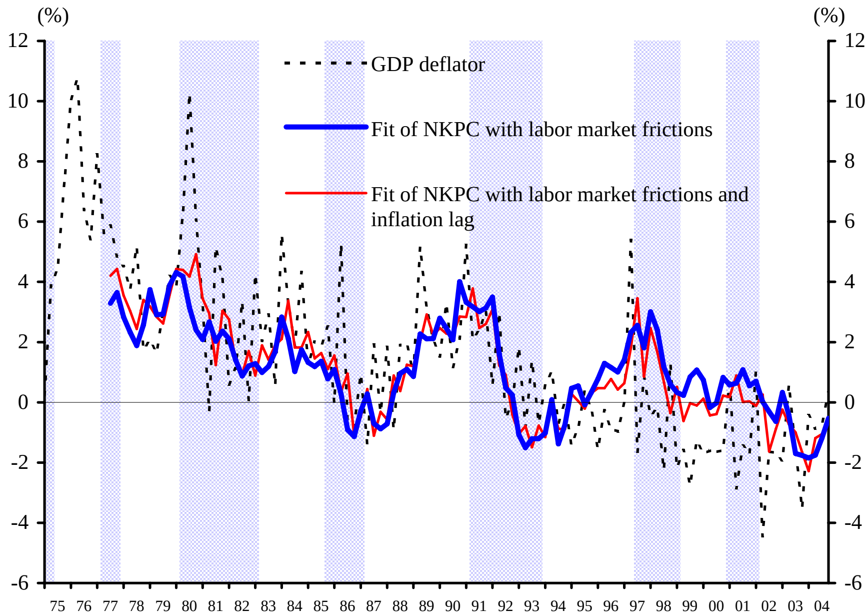
Note: The NKPC is based on the auxiliary VAR that includes $ln(S_t + \zeta_t)$ and EDI_t.

FIGURE 5: Benchmark NKPC with Inflation Lag



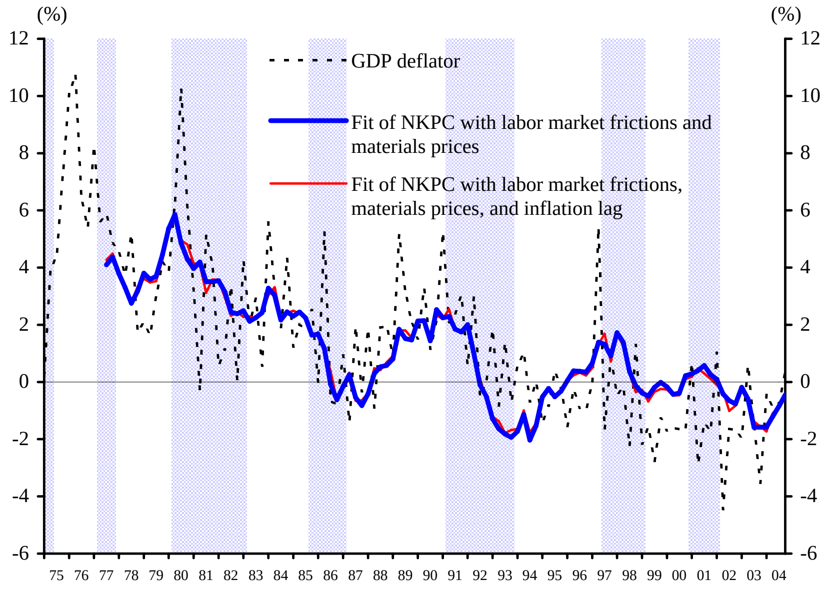
Note: The NKPC is based on the auxiliary VAR that includes only lnS_t.

FIGURE 6: NKPC with Labor Market Frictions and Inflation Lag



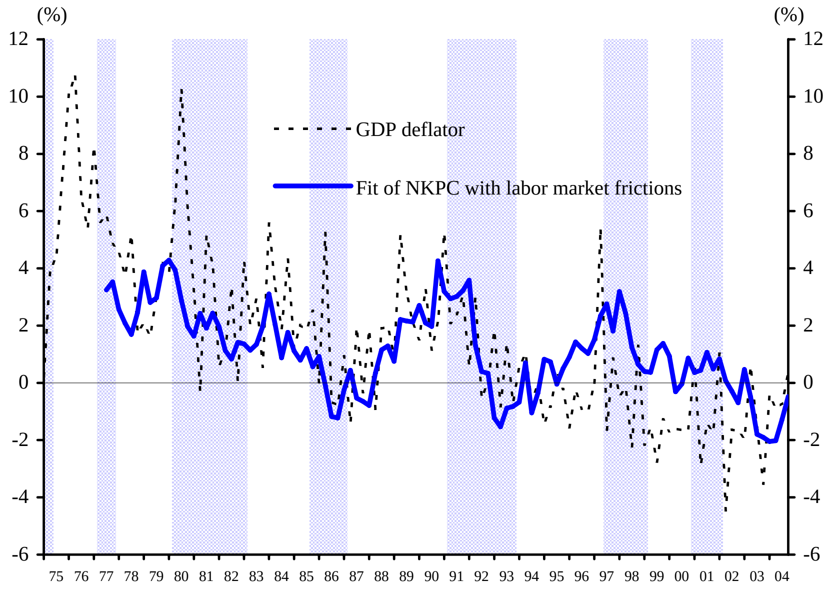
Note: The NKPC is based on the auxiliary VAR that includes $ln\,S_t$ and EDI_t.

FIGURE 7: NKPC with Labor Market Frictions, Materials Prices, and Inflation Lag



Note: The NKPC is based on the auxiliary VAR that includes $ln(S_t+\zeta_t)$ and EDI_t.

APPENDIX FIGURE: NKPC with Labor Market Frictions (With Model of Staggered Real Wage Setting)



Note: The NKPC is based on the auxiliary VAR that includes $ln(S_t)$ and EDI_t.