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Abstract

We estimate a New Keynesian Phillips curve (NKPC) for Japan's economy. To obtain a better proxy of real marginal cost (RMC), we correct labor share by incorporating labor adjustment costs, material prices, and real wage rigidity. Our approach is unique in utilizing the information on firms' judgment about the labor gap, which implies the existence of labor adjustment costs. Our results show that the NKPC explains Japanese inflation dynamics quite well if we use the corrected proxy of RMC. Furthermore, we find that Japanese inflation persistence is mostly accounted for by the persistence of RMC itself rather than lagged inflation.

Keywords: New Keynesian Phillips Curve; Real Marginal Cost; Labor Adjustment Cost; Material Price; Real Wage Rigidity; Inflation Persistence
JEL classification: E31

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1 Introduction

The New Keynesian Phillips curve (NKPC), developed by Rotemberg [1982a] and Calvo [1983], holds a central place in the recent literature on monetary economics.[1] In contrast to the traditional Phillips curve, the NKPC has a micro-foundation in which monopolistically competitive firms set prices based on their expectations regarding the future real marginal cost (RMC). Because this setup can avoid the well-known Lucas critique, most of the structural analyses of inflation dynamics or optimal monetary policies are now carried out within dynamic stochastic general equilibrium (DSGE) models, in which the NKPC, or a slightly modified version of it, typically plays a key role in determining the overall economic dynamics (Clarida, Gali, and Gertler [1999], Woodford [2003], Smets and Wouters [2003], Christiano, Eichenbaum, and Evans [2005], Levin et al. [2005], and many others).

Nevertheless, recent empirical studies by Rudd and Whelan [2005a,b,c, and 2006] show that if we use labor share (the real unit labor cost), which is the most conventional proxy of RMC, the performance of the NKPC is quite poor as regards the U.S. economy. Although some earlier studies (Gali and Gertler [1999], Woodford [2001], and Sbordone [2002]) have reported that the labor share-based NKPC explains well the inflation dynamics in the U.S., the series of studies by Rudd and Whelan repeatedly finds two kinds of shortcomings in the earlier studies. First, the results of some studies are quite sensitive to small changes in the specifications. Second, the results of the other studies are derived from inappropriate empirical methods. Following the exhaustive investigation, Rudd and Whelan [2005a] conclude, "the empirical evidence generally suggests that the labor share version of the new-Keynesian Phillips curve is a very poor model of price inflation" (p. 297).

However, their argument against the labor share version of the NKPC does not necessarily indicate that the NKPC is empirically invalid, because labor share might not be a good proxy of RMC. In fact, 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).[2] They explain 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. Therefore, their argument suggests a possibility that the fit of the NKPC can be improved if we correct labor share by incorporating some factors that break the theoretical correspondence between labor share and RMC.

In this study, we examine the empirical performance of the NKPC in explaining Japanese inflation dynamics, by focusing on the issue of measuring RMC.[3] We con-

[1] Calvo's model is in continuous time. The discrete-time version is developed by Yun [1996].

[2] Notice that markup is the inverse of RMC.

[3] Only a few studies estimate the Japanese NKPC, and these are obtainable only in Japanese.

sider that our analysis provides a good case study because, in the case of Japan, we can observe strong evidence that labor share is not a good proxy of RMC. 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).[4] The employment DI shows the net percentage of firms which consider that the current number of workers is excessive. Around the "bubble" period, nearly half of the Japanese firms considered that the number of workers was insufficient. After the bursting of the bubble, many firms had excessive labor for a long period. Thus, this series implies that 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.

The evidence of a substantial labor gap should better be incorporated into the measurement of Japan's RMC. As is explained by Rotemberg and Woodford [1999], labor share can be viewed as a good proxy of RMC only when firms attain the optimal number of workers without paying any adjustment cost. In this respect, the movements of the employment DI imply the existence of labor adjustment costs because we can reasonably consider that, if firms do not incur any adjustment cost, they can always attain the optimal number of workers.[5] Therefore, to calculate a better proxy of RMC, we need to correct labor share by incorporating labor adjustment costs.

In addition to labor adjustment costs, it might be important to take account of the influence of material prices in calculating RMC. In most of the previous studies, this issue is neglected, because the studies implicitly assume that firms attain the full arbitrage between the marginal cost of labor and the marginal cost of materials. However, Batini, Jackson, and Nickell [2005] show that, if the production technology requires a certain amount of materials to produce one additional unit of gross output, RMC on value added is calculated by correcting labor share with the relative price of materials to value added. Because some previous studies show that Japan's domestic inflation rate is significantly influenced by the price of imported materials, it would be better to incorporate the influence of material prices.[6]

Based on the above argument, to obtain a better proxy of RMC, we correct labor share by paying particular attention to the existence of labor adjustment costs and the influence of material prices (we call this a "labor share correction approach"). We consider that this kind of exercise is quite important, because the performance

Furthermore, none of these studies focus on the issue of how the correction to labor share is required to obtain a good proxy of RMC.

[4] 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).

[5] Of course, if the unemployment rate is equal to zero, this statement does not necessarily hold. However, the unemployment rate in Japan has been always positive, even during the bubble period.

[6] Higo and Nakada [1999] and Kamada and Masuda [2001] report that the changes in the price of imported goods have significantly influenced the domestic Japanese inflation rate, though these studies are based on the traditional Phillips curve.

of the NKPC can be properly evaluated only when we have a good proxy of RMC.

Our objective is very close to Batini, Jackson, and Nickell, who examine the importance of labor adjustment costs and material prices in calculating RMC of the U.K. However, our approach is unique in utilizing the information on firms' judgment about the labor gap, which implies the existence of labor adjustment costs. In our approach, we estimate (marginal) labor adjustment costs *without* specifying the exact form of the labor adjustment cost function. This approach has great merit since, as Rotemberg and Woodford [1999] describe, "while the existence of such adjustment cost is probably not controversial, their exact form and precise magnitude is far from having been settled"(p. 1130). Instead of specifying the form of the labor adjustment cost function, our approach requires us to specify the mechanism of real wage determination to derive the relationship between labor adjustment costs and the labor gap. In this respect, we take into account the existence of real wage rigidity, which can be regarded as the result of some imperfections or frictions in the labor market. We evaluate the importance of these factors by simultaneously estimating the NKPC and the degree of real wage rigidity.

As a result of this study, we can investigate the issue of inflation persistence. Many previous studies report that the purely forward-looking NKPC cannot explain the inflation persistence observed in the U.S. or the euro area (Fuhrer and Moore [1995], Fuhrer [1997, 2005], and Roberts [2005]). Because of this problem, some studies make a compromise to estimate the so-called "hybrid" NKPC, which includes a lagged inflation term as a "backward-looking" component (Gali and Gertler [1999] and Gali, Gertler and Lopez-Salido [2001, 2005a]). However, because these studies simply use labor share as the proxy of RMC, it is possible that these studies overestimate the importance of the lagged inflation term. Since our study uses a more sophisticated measure of RMC, we can more properly evaluate the importance of the lagged inflation term. Although we specifically analyze the case of Japan, our investigation provides a general implication for the literature that contributes to better understanding of the importance of the lagged inflation term.

The rest of this paper is organized as follows. In Section 2, we estimate the Japanese NKPC by using labor share as a proxy of RMC. In Section 3, we introduce labor adjustment costs in the calculation of RMC, and explain how the information on firms' judgment about the labor gap can be used to obtain a better proxy of RMC. In Section 4, we estimate the Japanese NKPC based on RMC, which is calculated in Section 3. In Section 5, we examine the influence of material prices in calculating RMC. In Section 6, we examine how the inclusion of the lagged inflation term improves the fit of the NKPC. In Section 7, we summarize our results.

2 The Japanese NKPC with Labor Share

In this section, as the starting point of this study, we estimate the Japanese NKPC by using labor share as the proxy of RMC. In the recent studies on the U.S. economy, Rudd and Whelan [2005a] show that, if we use labor share, the performance of the NKPC is quite poor. However, it is unclear whether this argument applies to the case of Japan, because the empirical studies of the Japanese NKPC are currently quite limited. Therefore, first we clarify this point.

Below, in Section 2.1, we derive the NKPC by using a simple framework in which labor share corresponds to RMC. Then, based on the framework, we estimate the Japanese NKPC by using labor share as the proxy of RMC in Section 2.2.

2.1 Simple Derivation of the NKPC with Labor Share

Consider the following aggregate production function, which is isoelastic with respect to aggregate labor input:[7]

$$Y_t = A_t L_t^{\alpha}, \tag{1}$$

where Y_t is aggregate value added, A_t is the exogenous shift factor, and L_t is the aggregate labor input. 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.

We assume that firms are perfectly competitive in the labor market. Therefore, nominal wages (W_t) are given to each firm. We further assume that the only variable cost is labor compensation ($W_t L_t$). Then, the cost minimization problem for the representative firm to produce some given amount of value added ($\overline{Y}_t$) is characterized by the following Lagrangean:

$$\pounds_t = W_t L_t + \lambda_t \left(\overline{Y}_t - A_t L_t^{\alpha} \right). \tag{2}$$

In this case, the Lagrangean can be written as a static form, since both of the production function and variable cost depend on the current number of workers in an intra-temporal way. The Lagrange multiplier λ_t represents nominal marginal cost, which is defined as the minimum additional cost (in nominal terms) to marginally increase value added. Therefore, from the first-order condition (FOC) with respect to L_t, real marginal cost (RMC_t) is calculated as follows:

$$RMC_t = \frac{\lambda_t}{P_t} = \frac{1}{\alpha} S_t, \tag{3}$$

[7] In this production function, we do not explicitly introduce hours. However, if the firm minimizes the cost of production, RMC must be equalized between different variable inputs (hours and employment). In this situation, we can abstract hours in (1).

where P_t is the price of value added and S_t is labor share ($S_t \equiv \frac{W_t L_t}{P_t Y_t}$). Thus, in this basic setup, RMC becomes proportional to labor share.

Next we consider the optimal price setting in the monopolistic competitive goods market. Before moving to the sticky price economy, we derive the optimal price under flexible prices (P_t^*). The standard profit maximization problem under monopolistic competition yields the following optimality condition:

$$P_t^* = \mu MC_t, \tag{4}$$

where μ is the markup and MC_t is the nominal marginal cost. Notice that μ is the so-called *desired markup* (or *equilibrium markup*), which is determined solely by the competitiveness of the goods market and is not affected by the degree of price stickiness.[8]

Next, we consider the sticky price economy. 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 cost as follows:

$$E_t \sum_{k=0}^{\infty} \beta^k \left[(\ln P_{t+k} - \ln P_{t+k}^*)^2 + \gamma (\ln P_{t+k} - \ln P_{t+k-1})^2 \right]. \tag{5}$$

Let P_t^s be the optimal price at t under sticky prices. Then, the FOC under sticky prices is as follows:

$$\ln \frac{P_t^s}{P_{t-1}^s} = \beta E_t \ln \frac{P_{t+1}^s}{P_t^s} + \frac{1}{\gamma} \ln \frac{P_t^*}{P_t^s}. \tag{6}$$

By substituting (4) into (6), we derive the NKPC with RMC as follows:

$$\pi_t = \beta E_t \pi_{t+1} + \frac{1}{\gamma} \ln \mu + \frac{1}{\gamma} \ln RMC_t, \tag{7}$$

where π_t is the inflation rate under sticky prices ($\pi_t \equiv \ln \frac{P_t^s}{P_{t-1}^s}$).

From (3) and (7), the NKPC with labor share is derived as follows:

$$\pi_t = \beta E_t \pi_{t+1} + \frac{1}{\gamma} \ln \frac{\mu}{\alpha} + \frac{1}{\gamma} \ln S_t. \tag{8}$$

2.2 Estimating the Japanese NKPC with Labor Share

Here we estimate the Japanese NKPC with labor share, which is derived as (8). In the literature, there exist two different methods for estimating the NKPC. The first is the generalized method of moments (GMM), which is used by Gali and Gertler

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

[1999], Gali, Gertler, and Lopez-Salido [2001, 2005a], and many others. The second is the estimation by using the present value model (PVM), which is employed by Woodford [2001] and Rudd and Whelan [2005a,b,c, 2006].[9] We choose the latter approach since it has the merit of not suffering from the well-known weak instrument problem of the GMM (Stock and Yogo [2002]), and because it is more robust than the GMM to the possible misspecifications in the determinants of expected inflation (Rudd and Whelan [2005b]).[10]

In the PVM, we first forecast the future path of RMC based on an auxiliary vector auto regression (VAR), and then use it to estimate the closed-form solution of the NKPC. To apply the PVM, by repeatedly substituting the expectation term of (8), we derive the closed-form solution of the NKPC as follows:

$$\pi_t = \frac{1}{\gamma(1-\beta)} \ln \frac{\mu}{\alpha} + \frac{1}{\gamma} E_t \sum_{k=0}^{\infty} \beta^k \ln S_{t+k}. \tag{9}$$

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

$$\mathbf{Z}_t = \mathbf{A}\mathbf{Z}_{t-1} + \boldsymbol{\epsilon}_t, \tag{10}$$

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. (10) represents a general form of VAR. 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:

$$\sum_{k=0}^{\infty} \beta^k E_t \ln S_{t+k} = e_1'(\mathbf{I} - \beta\mathbf{A})^{-1}\mathbf{Z}_t, \tag{11}$$

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

$$\pi_t = a_0 + a_1 e_1'(\mathbf{I} - \beta\mathbf{A})^{-1}\mathbf{Z}_t, \tag{12}$$

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 NKPC with labor share. We can simply estimate (12) by ordinary least squares (OLS).[11]

[9] The PVM was used originally by Campbell and Shiller [1987] in the context of stock price determination. Although Sbordone [2002] uses the same approach in the first step of generating the forecast of labor share, her estimation form at the second stage is quite different from that of Woodford [2001] or Rudd and Whelan [2005a,b,c, 2006]. Rudd and Whelan [2005a] criticize Sbordone's methodology on the grounds that her estimation form is invalid in testing the NKPC against alternative models and it actually fits inflation rate quite well no matter which measure of RMC is used.

[10] See Mavroeidis [2005] for the weak identification problem in the context of the NKPC. Rudd and Whelan [2005b] show that the GMM estimation employed by Gali and Gertler [1999] spuriously indicates the presence of forward-looking behavior when such behavior is not actually present.

[11] Since we assume that (10) is the true data generating process of labor share, we may ignore the endogeneity problem in estimating (12).

As for the data on 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 employees in self-employed firms.[12] For this reason, we use the following definition recommended by Batini, Jackson, and Nickell [2000] and Kamada and Masuda [2001]:

$$labor\ share = \frac{compensation\ of\ employees}{national\ income{-}households'\ operating\ surplus}.$$

This definition assumes that labor share in self-employed firms is just the same as that in other firms. These series are shown in Figure 2.[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 three multivariate models, which have the combinations of the (log of) labor share, growth of unit labor cost, and inflation.[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.

Table 1 summarizes the estimation results. For each VAR specification, the fit of the NKPC is quite poor, since $Adj\text{-}R^2$ is just around 0.1 or 0.2 and there is noticeable serial correlation in the error term.[15] In Figure 3, we can graphically confirm that the fit of the NKPC is quite poor, because it cannot explain the inflationary pressure around the bubble period and the deflationary trend after the bursting of the bubble.

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

3 RMC with Labor Adjustment Costs: A Labor Share Correction Approach

In this section, we examine the possibility that labor share does not appropriately represent the movement of RMC. In doing so, we focus particularly on how the

[12] This issue is noted by many studies, such as Krueger [1999] and Bentolila and Saint-Paul [1999].

[13] See appendix 5 of Kamada and Masuda [2001] for the alternative series of Japan's labor share.

[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. However, Rudd and Whelan [2005a] show that this result is very sensitive to the inclusion of other variables, such as detrended output and detrended hours.

[15] As Kurmann [2005] points out, standard errors on the estimated coefficients will be underestimated, because we neglect the standard errors in the auxiliary VAR. Therefore, we believe that the fit of the NKPC in the point estimates (expressed as $Adj\text{-}R^2$) is more meaningful in this study.

existence of labor adjustment costs influences the measurement of RMC.

The concept of labor adjustment costs has been introduced into the literature of labor economics to explain the slow adjustment of labor demand.[16] Nevertheless, many of the previous empirical studies on the NKPC neglect it in calculating RMC, as if they assume that firms do not incur any cost in changing the number of workers. The reason for this can be attributed largely to the difficulty of measuring labor adjustment costs. As Hamermesh and Pfann (1996) explain, "one wonders why it should not be easy to obtain information on the sources and sizes of adjustment costs. The reason is probably that many of these costs are implicit, in that they result in lost output and are thus not measured and reported on an income and expenditure statement generated by the firm's accounts"(p. 1267).

To gauge the magnitude of labor adjustment costs, some previous studies (such as Batini, Jacksosn, and Nickell [2005]) have specifically focused on the symmetric quadratic function of the change of the number of workers.[17] However, there is ample evidence that the cost of adjusting employees at the plant level is at least asymmetric or lumpy, and cannot be represented by symmetric quadratic form (Pfann and Palm [1993], Hamermesh [1989]. and many others). Even at the aggregate level, the question of whether such a symmetric quadratic form can approximate the aggregate labor adjustment cost function is highly controversial (Caballero and Engel [1993, 2004], Caballero, Engel, and Haltiwanger [1997], Cooper and Willis [2002, 2004a,b], Cooper, Haltiwanger, and Willis [2003]).

Therefore, it is unclear whether some particular functional form captures the nature of aggregate labor adjustment costs. However, as explained in Section 1, we have good information on firms' judgment about the labor gap, which implies the existence of labor adjustment costs. Therefore, we propose an approach to utilize the information on firms' judgment about the labor gap to calculate labor adjustment costs.

3.1 Introducing Labor Adjustment Costs

Here we explain how the introduction of labor adjustment costs influences the calculation of RMC. Define Ω_t as the representative firm's (nominal) labor adjustment costs. 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 ($\Omega_t = \Omega_t(L_t, L_{t-1}, L_{t-2}, \cdots)$).[18]

[16] Hamermesh and Pfann [1996] and Nickell [1986] give detailed explanations on the sources of the labor adjustment costs.

[17] Sbordone [2002, 2005] introduces a quadratic labor adjustment cost function and concludes that the introduction of labor adjustment cost does not greatly alter the fit of the NKPC. However, her labor adjustment cost function depends on the growth of hours, not the growth of workers. Since previous empirical studies, such as Sargent [1978] and Shapiro [1986], show that there are no adjustment costs in hours, we believe that Sbordone's result is unsurprising.

[18] Some readers may wonder why Ω_t depends on the labor prior to time $t-1$ ($L_{t-2}, L_{t-3}, \cdots$). The reasons are twofold. First, firms might have to incur training cost and the cost of re-organization

Since Ω_t inter-temporally depends on labor input, the firm's cost-minimization problem becomes dynamic. Then, the Lagrangean can be expressed as follows:

$$\pounds_t = E_t \sum_{k=0}^{\infty} \beta^k [W_{t+k} L_{t+k} + \Omega_{t+k} + \lambda_{t+k} (\overline{Y}_{t+k} - A_{t+k} L_{t+k}^{\alpha})], \tag{13}$$

where β is the discount factor.

From the FOC with respect to L_t, RMC at period t is calculated as follows:

$$RMC_t = \frac{\lambda_t}{P_t} = \frac{1}{\alpha} S_t \left[1 + \frac{1}{W_t} E_t \sum_{k=0}^{\infty} \beta^k \left(\frac{\partial \Omega_{t+k}}{\partial L_t} \mid_{L_{t+k}=L_{t+k}^* \ \forall\ k} \right) \right], \tag{14}$$

where L_t^* is the optimal number of workers at t.[19,20]

Note that, in the special case where the expected discounted sum of 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 becomes proportional to labor share. But if it is nonzero, RMC does not correspond to labor share. Therefore, to obtain a better proxy of RMC, we need to estimate the partial derivatives of Ω_t. However, if we have the information on the labor gap, which is defined as the deviation of the actual number of workers from the optimal number of workers, we can indirectly estimate the magnitude of marginal labor adjustment costs without specifying the exact form of Ω_t. Below we explain how the information on the labor gap can be utilized to estimate the marginal labor adjustment costs.

3.2 Relationship between Labor Adjustment Costs and the Labor Gap

3.2.1 Setup of the Household

In deriving the relationship between (marginal) labor adjustment costs and the labor gap, we need to explicitly introduce the utility function of the representative household. This is because the relationship depends on the shape of the labor supply function, especially in the case where real wages are perfectly flexible.

Put concretely, we consider the following standard instantaneous utility function of a representative household:

$$U_t = \frac{Y_t^{1-\sigma}}{1-\sigma} - \frac{1}{\eta} L_t^{\eta}. \tag{15}$$

for more than one period. Second, if individual labor adjustment cost functions are asymmetric, we encounter the problem of time aggregation, which produces bias in the estimated lag length (Hamermesh and Pfann [1996]).

[19] In the argument of a later subsection, L_t^* corresponds to the optimal number of workers under flexible prices.

[20] Here we implicitly assume that W_t is a convex function of hours per employee. This assumption is necessary because, if W_t is a linear function of hours, it is always optimal for the firm to change the production solely by adjusting hours.

From the standard utility maximization problem, real wages must be equalized to the marginal rate of substitution between consumption and labor. Therefore, it yields the following labor supply function:

$$\ln \frac{W_t}{P_t} = \ln Y_t^{\sigma} L_t^{\eta-1}. \tag{16}$$

In the following, we derive the relationship between labor adjustment costs and the labor gap, based on the labor supply function (16).

3.2.2 Flexible Price Economy

Our goal in this subsection is to derive the relationship between labor adjustment costs and the labor gap under sticky prices. For this purpose, we take the following two-step approach. As the first step, we derive the relationship between labor adjustment costs and the labor gap under flexible prices. Then, as the second step, we derive the relationship between the labor gap under a flexible price economy and the labor gap under a sticky price economy. Here, we carry out the first step.

From (1), (4), (14), and (16), we can calculate the optimal number of workers under flexible prices (denoted as L_t^*) as follows:

$$L_t^* = \left[\frac{\mu}{\alpha} A_t^{\sigma-1} \left(1 + \frac{1}{W_t} E_t \sum_{k=0}^{\infty} \beta^k \left(\frac{\partial \Omega_{t+k}}{\partial L_t} \,|_{L_{t+k}=L_{t+k}^* \; \forall \; k}\right)\right)\right]^{\frac{1}{\alpha(1-\sigma)-\eta}}. \tag{17}$$

Thus, L_t^* depends on the partial derivatives of Ω_t. This result is quite intuitive, because L_t^* is defined as the optimal number of workers in the presence of labor adjustment costs. From (17), we can also calculate the optimal number of workers in the absence of labor adjustment costs (denoted as $\overline{L}_t^*$) as follows:

$$\overline{L}_t^* = \left(\frac{\mu}{\alpha} A_t^{\sigma-1}\right)^{\frac{1}{\alpha(1-\sigma)-\eta}}. \tag{18}$$

Since the labor gap under flexible prices ($LGAP_t^*$) is defined as the log-difference between L_t^* and $\overline{L}_t^*$ ($LGAP_t^* \equiv \ln L_t^* - \ln \overline{L}_t^*$), the relationship between labor adjustment costs and the labor gap under flexible prices is derived as follows:

$$\ln \left[1 + \frac{1}{W_t} E_t \sum_{k=0}^{\infty} \beta^k \left(\frac{\partial \Omega_{t+k}}{\partial L_t} \,|_{L_{t+k}=L_{t+k}^* \; \forall \; k}\right)\right] = [\alpha(1-\sigma)-\eta]\, LGAP_t^*. \tag{19}$$

3.2.3 Sticky Price Economy

As the second step, we derive the relationship between the labor gap under flexible prices and the labor gap under sticky prices. From the production function (1) and labor supply function (16), we obtain

$$\ln P_t = (1 - \eta - \alpha\sigma) \ln L_t + \ln W_t - \sigma \ln A_t. \tag{20}$$

Therefore, from (6) and (20), we derive the condition about the optimal number of workers under sticky prices in the presence of labor adjustment costs as follows:

$$\ln \frac{L_t^s}{L_{t-1}^s} = \beta E_t \ln \frac{L_{t+1}^s}{L_t^s} + \frac{1}{\gamma} \ln \frac{L_t^*}{L_t^s} + \Gamma_t, \tag{21}$$

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.[21] Similarly, we can derive the condition about the optimal number of workers under sticky prices in the absence of labor adjustment costs as follows:

$$\ln \frac{\overline{L}_t^s}{\overline{L}_{t-1}^s} = \beta E_t \ln \frac{\overline{L}_{t+1}^s}{\overline{L}_t^s} + \frac{1}{\gamma} \ln \frac{\overline{L}_t^*}{\overline{L}_t^s} + \Gamma_t, \tag{22}$$

where $\overline{L}_t^s$ is the optimal number of workers under sticky prices in the absence of labor adjustment costs. The labor gap under sticky prices ($LGAP_t^s$) is defined as the log-difference between L_t^s and $\overline{L}_t^s$ ($LGAP_t^s \equiv \ln L_t^s - \ln \overline{L}_t^s$). Therefore, by subtracting (22) from (21), we can derive the relationship between the labor gap under flexible prices ($LGAP_t^*$) and the labor gap under sticky prices ($LGAP_t^s$) as follows:

$$LGAP_t^* = (1 + \gamma + \gamma\beta) LGAP_t^s - \gamma LGAP_{t-1}^s - \gamma\beta E_t LGAP_{t+1}^s. \tag{23}$$

Thus, $LGAP_t^*$ and $LGAP_t^s$ are dynamically linked by the structural parameters, such as γ and β. From (14), (19), and (23), we finally derive the expression of RMC in terms of $LGAP_t^s$ as follows:

$$\begin{aligned} \ln RMC_t &= \ln \frac{1}{\alpha} + \ln S_t + [\alpha(1-\sigma) - \eta] \\ &\quad \left[(1 + \gamma + \gamma\beta) LGAP_t^s - \gamma LGAP_{t-1}^s - \gamma\beta E_t LGAP_{t+1}^s\right]. \end{aligned} \tag{24}$$

Thus, the above representation of RMC includes the terms of the lagged labor gap ($LGAP_{t-1}^s$) and the expectation for future labor gap ($E_t LGAP_{t+1}^s$). These terms emerge because firms' FOC under sticky prices (6) includes lagged prices (P_{t-1}^s) and the expectation for future prices ($E_t P_{t+1}^s$), and, in the case of perfectly flexible real wages, the household's labor supply function relates price and labor in an intra-temporal way. As a result, current, past and the future labor gaps are linked by the parameters of price stickiness (γ) and the discount factor (β). Since these parameters

[21] Γ_t is defined as follows:
$\Gamma_t = \frac{1}{1-\eta-\alpha\sigma}\left[-\left(\ln \frac{W_t}{W_{t-1}} - \sigma \ln \frac{A_t}{A_{t-1}}\right) + \beta\left(\ln \frac{E_t W_{t+1}}{W_t} - \sigma \ln \frac{E_t A_{t+1}}{A_t}\right)\right].$
In this study, we assume that the level of nominal wage (W_t) is purely exogenous.

cannot be estimated independently from the parameters of the NKPC, we estimate them by jointly estimating the NKPC in Section 4.

3.3 Influence of Real Wage Rigidity

In the previous subsection, we have derived (24) under an implicit assumption that real wages are perfectly flexible. However, this assumption might be unrealistic, because it implies that the labor market is perfectly efficient and unemployment does not arise as the result of inefficient allocation between firms and workers. In addition, Christiano, Eichenbaum and Evans [1999] show that sticky price models with perfectly flexible wages cannot replicate the sluggish response of real wages to a tightening of monetary policy, which is typically observed in VAR analysis. Moreover, Erceg, Henderson, and Levin [2000] and Blanchard and Gali [2005] argue that such models do not have any essential trade-off between inflation and the output gap.

Actually, this issue is quite important in our analysis, since the dynamic relationship between labor adjustment costs and the labor gap depends crucially on the mechanism of real wage determination. In the case of perfectly flexible wages, real wages are set to be equal to the marginal rate of substitution between consumption and labor, as shown in (16). However, if there is real wage rigidity, the relationship of (16) does not hold. In this case, the movements of real wages become more sluggish than that of the marginal rate of substitution between consumption and labor. From this reasoning, we apply the following partial adjustment process of real wages, which is introduced by Blanchard and Gali [2005] and Christoffel and Linzert [2005]:

$$\ln \frac{W_t}{P_t} = \rho \ln \frac{W_{t-1}}{P_{t-1}} + (1-\rho) \ln Y_t^{\sigma} L_t^{\eta-1}, \tag{25}$$

where ρ characterizes the degree of real wage rigidity.[22] Notice that, in the limiting case of $\rho = 0$, (25) corresponds to the labor supply function (16). Although this partial adjustment process does not characterize some particular imperfections or frictions in the labor market, Blanchard and Gali [2005] explain that this model is "an admittedly ad-hoc but parsimonious way of modeling the slow adjustment of wages to labor market conditions, as found in a variety of models of real wage rigidities, without taking a stand on what a right model is"(p. 9). Because our study does not intend to specify the cause of imperfections or frictions in the labor market, we adopt this partial adjustment process.[23] However, in Appendix A, we check the robustness of our analysis by introducing a micro-founded model of staggered real

[22] As a related concept to real wage rigidity, Gali, Gertler, and Lopez-Salido [2001, 2005b] introduce the concept of "wage markup," which is calculated as the deviation of real wages from the marginal rate of substitution between consumption and labor. Chari, Kehoe, and McGrattan [2004] define the deviation of the marginal product of labor from the marginal rate of substitution between consumption and labor as a "labor wedge" in their framework of business cycle accounting.

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

wage setting, which is presented in appendix 2 of Blanchard and Gali [2005].

By repeated substitution, (25) can be rewritten as

$$\ln \frac{W_t}{P_t} = \frac{1-\rho}{1-\rho B} \ln Y_t^{\sigma} L_t^{\eta-1}, \tag{26}$$

where B is the backshift operator.[24]

Using (1), (4), (14), (21), (22), and (26), we can derive the relationship between RMC and the labor gap under sticky prices as follows:

$$\begin{aligned} \ln RMC_t &= \ln \frac{1}{\alpha} + \ln S_t + \left[\alpha - 1 - \frac{(\alpha\sigma + \eta - 1)(1-\rho)}{1-\rho B} \right] \\ &\quad \left[(1+\gamma+\gamma\beta) LGAP_t^s - \gamma LGAP_{t-1}^s - \gamma\beta E_t LGAP_{t+1}^s \right]. \end{aligned} \tag{27}$$

Notice that the coefficient on the third term of the right-hand side includes backshift operator B. Consequently, in the case of $\rho \neq 0$, the dynamic relationship between RMC_t and $LGAP_t^s$ in (27) becomes different from that in (24). Therefore, if the degree of real wage rigidity is large, RMC is quite persistently influenced by the series of the labor gap. In the next section, we check the importance of real wage rigidity in Japan by estimating the value of ρ.

4 The Japanese NKPC with RMC

In this section, we estimate the Japanese NKPC with RMC, which was calculated in the previous section. Below, we first estimate it in the case without real wage rigidity. Then, we estimate it in the case with real wage rigidity.

4.1 Without Real Wage Rigidity

In Section 2.3, we derived the expression of RMC in terms of the labor gap under sticky prices as (24). This expression enables us to utilize the information on the labor gap. As a proxy for the labor gap, we use the employment DI, which is explained in Section 1. Since the actual Japanese economy is assumed to be under sticky prices, we can reasonably assume the following relationship:

$$LGAP_t^s = \delta EDI_t, \tag{28}$$

[24] 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.

where EDI_t is the employment DI. Then, from (7), (24), and (28), we derive the following expression of the NKPC with RMC in the case without real wage rigidity:

$$\begin{aligned}\pi_t &= \beta E_t \pi_{t+1} + \frac{1}{\gamma}\ln\frac{\mu}{\alpha} + \frac{1}{\gamma}\ln S_t + \frac{\delta\left[\alpha(1-\sigma)-\eta\right]}{\gamma} \\ &\quad \left[(1+\gamma+\gamma\beta)EDI_t - \gamma EDI_{t-1} - \gamma\beta E_t EDI_{t+1}\right]. \end{aligned} \tag{29}$$

As in Section 2.2, we estimate (29) using the PVM. In doing so, we replace the matrix $\mathbf{Z}_t$ in (10) to include $\ln S_t$ as the first and EDI_t as the second variable. Then, the closed-form solution of (29) is represented as follows:

$$\pi_t = b_0 + b_1 e_1'(\mathbf{I}-\beta\mathbf{A})^{-1}\mathbf{Z}_t + b_2\left[b_1 e_2'(\mathbf{I}-\beta\mathbf{A})^{-1}\mathbf{Z}_t + EDI_t - EDI_{t-1}\right], \tag{30}$$

where $b_0 = \frac{1}{\gamma(1-\beta)}\ln\frac{\mu}{\alpha}$, $b_1 = \frac{1}{\gamma}$, $b_2 = \delta\left[\alpha(1-\sigma)-\eta\right]$, 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 and the sample period are the same as in Section 2.2.

Table 2 shows the estimation results of (30). For each VAR specification, the fit of the NKPC with RMC is better than that of the NKPC with labor share. This means that the poor fit of the NKPC with labor share, which is presented in Table 1, is at least partially attributable to the ignorance about labor adjustment costs.

Thus, the results suggest that labor adjustment costs are relevant. However, Figure 4 shows that the improvement in the fit of the NKPC with RMC is not particularly remarkable. It still has difficulty explaining the inflationary pressure around the bubble period and the deflationary trend after the bursting of the bubble. Nevertheless, we can further consider that this result is largely attributable to the assumption of perfectly flexible real wages. In the following, we estimate the NKPC with RMC in the case with real wage rigidity.

4.2 With Real Wage Rigidity

In the presence of real wage rigidity, RMC with labor adjustment costs is calculated as (27). By inserting (27) and (28) into (7), we obtain the NKPC with RMC in the case with real wage rigidity as follows:

$$\begin{aligned}\pi_t &= \beta E_t \pi_{t+1} + \frac{1}{\gamma}\ln\frac{\mu}{\alpha} + \frac{1}{\gamma}\ln S_t + \frac{\delta}{\gamma}\left[\alpha - 1 - \frac{(\alpha\sigma+\eta-1)(1-\rho)}{1-\rho B}\right] \\ &\quad \left[(1+\gamma+\gamma\beta)EDI_t - \gamma EDI_{t-1} - \gamma\beta E_t EDI_{t+1}\right]. \end{aligned} \tag{31}$$

We estimate (31) by using the PVM. In doing so, we use the VAR system estimated in the previous subsection. Then, the closed-form solution of (31) is derived as

$$\begin{aligned}\pi_t &= c_0 + c_1 e_1'(\mathbf{I}-\beta\mathbf{A})^{-1}\mathbf{Z}_t + c_2\left[c_1 e_2'(\mathbf{I}-\beta\mathbf{A})^{-1}\mathbf{Z}_t + EDI_t - EDI_{t-1}\right] \\ &\quad + c_3\sum_{h=0}^{\overline{h}}\rho^h\left[c_1 e_2'(\mathbf{I}-\beta\mathbf{A})^{-1}\mathbf{Z}_{t-h-1} + EDI_{t-h-1} - EDI_{t-h-2}\right], \qquad (32)\end{aligned}$$

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

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 $\overline{h}$.

Table 3 shows the estimation results of (32). Compared to Table 2, 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 means that real wages are quite rigid in Japan. Figure 5 clearly shows that the introduction of real wage rigidity remarkably improves the fit of the NKPC. The NKPC now explains the inflationary pressure around the bubble period.

Thus, the results in this section show that, if we correct labor share by incorporating labor adjustment costs, the NKPC with RMC can explain Japanese inflation dynamics remarkably well. We also find that real wage rigidity is a key element in determining the relationship between labor adjustment costs and the labor gap.[25]

5 Influence of Material Prices

So far, we have not explicitly considered the influence of material prices in the calculation of RMC. This is because, as in many previous studies, we have implicitly assumed the full arbitrage between the marginal cost of labor and the marginal cost of material input. However, if production technology requires a certain amount of materials to produce one additional unit of gross output, material prices might influence RMC on value added.

This issue is raised by Batini, Jackson, and Nickell [2000, 2005]. They consider the following production function of gross output:

$$Q_t = \min\left(A_t L_t^{\alpha},\ M_t\right) \qquad (33)$$

and

$$M_t = m(Q_t)Q_t, \text{ where } m'(Q_t) \geq 0, \qquad (34)$$

[25] Based on the framework of business cycle accounting developed by Chari, Kehoe, and McGrattan [2004], Kobayashi and Inaba [2005] 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. Their finding is consistent with our results, which suggest labor adjustment costs and real wage rigidity are quite important in the Japanese economy.

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

(33) 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 (34). (34) means that the required ratio of material input to gross output (m) depends on the level of gross output (Q_t). This corresponds to the following situation. 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. Until the previous section, we have implicitly assumed that m does not depend on Q_t ($m'(Q_t) = 0$). Now, it is nested as a special case of (34).

In this generalized setup, RMC is influenced by the relative price of materials to value added. Batini, Jackson, and Nickell show that RMC on value added additionally includes the following term:

$$\zeta_t = \varepsilon_m \frac{P_{M,t} M_t}{P_t Q_t}, \tag{35}$$

where $P_{M,t}$ is the price of materials and ε_m is the elasticity of M_t/Q_t to Q_t (Appendix B for the derivation of ζ_t).

To check the importance of ζ_t, we estimate the elasticity ε_m. For this purpose, we construct a quarterly series of material inputs and the material prices, following the interpolation method of Chow and Lin [1971].[26] The series of relative prices of material input to value added ($P_{M,t}/P_t$) is presented in Figure 6.

Table 4 presents 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. RMC in the case with real wage rigidity must be modified as follows:

$$\begin{aligned} \ln RMC_t \;=\; & \ln(\frac{S_t}{\alpha} + \zeta_t) + \left[\alpha - 1 - \frac{(\alpha\sigma + \eta - 1)(1-\rho)}{1 - \rho B}\right] \\ & \left[(1 + \gamma + \gamma\beta) LGAP_t^s - \gamma LGAP_{t-1}^s - \gamma\beta E_t LGAP_{t+1}^s\right]. \end{aligned} \tag{36}$$

We again use the PVM to estimate the NKPC with RMC, following the expression of (36). In the VAR of (10), 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

[26] To estimate the quarterly series of material 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.

modified as follows:

$$\pi_t = d_0 + d_1 e_1'(\mathbf{I}-\beta\mathbf{A})^{-1}\mathbf{Z}_t + d_2\left[c_1 e_2'(\mathbf{I}-\beta\mathbf{A})^{-1}\mathbf{Z}_t + EDI_t - EDI_{t-1}\right]$$
$$+d_3\sum_{h=0}^{\overline{h}}\rho^h\left[c_1 e_2'(\mathbf{I}-\beta\mathbf{A})^{-1}\mathbf{Z}_{t-h-1} + EDI_{t-h-1} - EDI_{t-h-2}\right], \qquad (37)$$

where $d_0 \simeq \frac{1}{\gamma(1-\beta)}\left(\ln\frac{\mu}{\alpha}+\ln\overline{\zeta}\right)$, $d_1 = \frac{1}{\gamma}$, $d_2 = \delta\left[(\alpha-1)-(\alpha\sigma+\eta-1)(1-\rho)\right]$, and $d_3 = -\delta(\alpha\sigma+\eta-1)(1-\rho)\rho$.[27]

The estimation results are presented in Table 5. The fit of the NKPC is further improved over Table 3 for every specification of VAR. Now we do not have noticeable serial correlation in the error term (see Figure 7 for the fit of the NKPC). Therefore, this result suggests that Japanese inflation dynamics are well explained within the framework of the NKPC, if we calculate RMC by incorporating three components: (i) labor share, (ii) labor adjustment costs, and (iii) the influence of material prices.

6 How Important is Lagged Inflation?

In the preceding sections, we have seen that, if we correct labor share by incorporating labor adjustment costs and material prices, the performance of the Japanese NKPC is remarkably improved. In particular, in Table 5, we find that serial correlation is very scarce in the error term. In comparison with the previous literature, this result is striking, since most of the empirical studies of the NKPC on the U.S. or the euro area report that the purely forward-looking NKPC cannot fully account for the observed persistence of the inflation rate. Because of this problem, many studies make a compromise to estimate the so-called "hybrid" NKPC, which includes a lagged inflation term as a "backward-looking" component.

The distinguishing feature of our study lies in the measurement of RMC. Whereas most of the previous studies simply use labor share, our study more seriously calculates RMC by incorporating labor adjustment costs and material prices. Naturally, this different treatment of RMC yields different results about the importance of lagged inflation between in comparison with previous studies.

To check this point, we again estimate the closed-form solutions of the NKPC with labor share and RMC, which are expressed in (12), (30), (32), and (37) by additionally including the lagged inflation term. This estimation form can be understood as the closed-form solution of the "hybrid" NKPC, which additionally includes the lagged inflation term in the structural form of (7).[28]

Table 6 shows the estimation results of the hybrid NKPC when we use labor share as the proxy of RMC. In this table, we find that the coefficient on lagged inflation

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

[28] Rudd and Whelan [2006] analytically derive the closed-form solution of the hybrid NKPC.

is close to 0.5 in every VAR specification and $Adj\text{-}R^2$ is much larger than in Table 1. In Figure 8, we also find that, by including the lagged inflation term, the fit of the NKPC with labor share is largely altered. Therefore, if we use labor share as the proxy of RMC, lagged inflation plays an important role in the case of Japan. This situation is the same as in the U.S or the euro area.

However, Tables 7 and 8 show that, if we correct labor share by incorporating labor adjustment costs, lagged inflation becomes less important. Furthermore, Table 9 shows that, if we take account of the influence of material prices, the coefficient of lagged inflation now becomes quite small (around 0.1) in every VAR specification. Figure 9 shows that the fits of the NKPC are almost the same in the two cases, with and without the lagged inflation term. This result suggests that, if we obtain a better proxy of RMC by incorporating labor adjustment costs and the influence of material prices, the lagged inflation term does not play any essential role. Therefore, Japanese inflation persistence is explained mostly by the persistence of RMC itself.

7 Conclusions

In this study, we have estimated the New Keynesian Phillips curve (NKPC) for Japan's economy. To obtain a better proxy of real marginal cost (RMC), we have corrected labor share by incorporating labor adjustment costs, material prices, and real wage rigidity. Our approach is unique in utilizing the information on firms' judgment about the labor gap, which implies the existence of labor adjustment costs.

The main findings are summarized as follows. First, if we use labor share, the performance of the Japanese NKPC is quite poor, which suggests that labor share is not a good proxy of RMC in Japan. Second, if we correct labor share by incorporating labor adjustment costs with considering the existence of real wage rigidity, the fit of the NKPC is remarkably improved. Third, if we additionally incorporate the influence of material prices, the fit of the Japanese NKPC is further improved, and the resulting persistence of RMC accounts for most of the Japanese inflation persistence. These findings suggest that the NKPC is a useful framework for explaining Japanese inflation dynamics if we use a better proxy of RMC by incorporating labor adjustment costs, real wage rigidity, and the influence of material prices.

Although we have specifically analyzed the case of Japan, our results have general implications for the literature. Most of the empirical studies about the U.S. or the euro area examine the fit of the NKPC only by using labor share. Among them, some recent studies (Rudd and Whelan [2005a,b,c, and 2006]) point out that the performance of the NKPC is quite poor, and many (such as Fuhrer and Moore [1995] and Roberts [2005]) have made the criticism that the NKPC cannot explain the observed inflation persistence. However, it is too early to accept their argument, because there are good reasons to consider that labor share is not a good proxy of RMC (Rotemberg and Woodford [1999]). In fact, some empirical studies on the markup variations in the industry level, such as Bils [1987] and Bils and Kahn [2000], show that RMC is actually pro-cyclical, even in the U.S., by estimating the marginal wage schedule.

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. From this viewpoint, it is quite probable that labor share needs to be corrected even in other countries. Therefore, to obtain a better understanding of the mechanism of inflation dynamics, researchers should make further efforts to find a better proxy of RMC.

Appendix A: The Japanese NKPC with RMC Based on a Model of Staggered Real Wage Setting

We check the robustness of our results by using a micro-founded model of real wage rigidity. For this purpose, we introduce a model of staggered real wage setting, which is derived in appendix 2 of Blanchard and Gali [2005]. Denote ω_t as the log of the aggregate real wage at time t. In every period, a fraction $1-\varphi$ of workers resets their wages. Log-linearization yields the following motion of ω_t:

$$\omega_t = \varphi\omega_{t-1} + (1-\varphi)\omega_t^*, \tag{A1}$$

where ω_t^* is the log of the newly set real wages at period t.

Utility maximization leads to the following real wage-setting rule:

$$\omega_t^* = (1-\beta\varphi)\sum_{k=0}^{\infty}(\beta\varphi)^k E_t mrs_{t+k|t}, \tag{A2}$$

where $mrs_{t+k|t}$ is the (log of) the marginal rate of substitution for a worker who last set his or her wages in period t. Under the assumption of imperfect substitutability between workers in production, the following relationship between $mrs_{t+k|t}$ and the aggregated marginal rate of substitution at period $t+k$ (mrs_{t+k}) holds:

$$mrs_{t+k|t} = mrs_{t+k} - \varepsilon_\omega(\eta-1)(\omega_{t+k}^* - \omega_{t+k}), \tag{A3}$$

where ε_ω is the wage elasticity of labor demand for an individual worker and η is the labor supply elasticity in the utility function.

Then, by substituting (A3) into (A2), we obtain the following equation:

$$\begin{aligned}\omega_t^* &= (1-\beta\varphi)\sum_{k=0}^{\infty}(\beta\varphi)^k E_t\left[mrs_{t+k} - \varepsilon_\omega(\eta-1)(\omega_{t+k}^* - \omega_{t+k})\right] \\ &= \beta\varphi E_t\omega_t^* + \frac{1-\beta\varphi}{1+\varepsilon_\omega(\eta-1)}\left[mrs_t + \varepsilon_\omega(\eta-1)\omega_t\right]. \end{aligned} \tag{A4}$$

Combining (A1) and (A4), we obtain

$$\omega_t = \Phi\omega_{t-1} + \Phi\beta E_t\omega_{t+1} + \Lambda mrs_t, \tag{A5}$$

where $\Phi \equiv \frac{(1+\varepsilon_\omega(\eta-1))\varphi}{1+\varphi(\varepsilon_\omega(\eta-1)(1+\beta)+\beta\varphi)}$ and $\Lambda \equiv \frac{(1-\beta\varphi)(1-\varphi)}{1+\varphi(\varepsilon_\omega(\eta-1)(1+\beta)+\beta\varphi)}$.

Therefore, the real wages depend on forward-looking expectation ($E_t\omega_{t+1}$). This feature differs from the partial adjustment model used in Section 3.3. By using backshift operator (B), (A5) can be rewritten as follows:

$$\omega_t = (1-\xi\beta B^{-1})^{-1}(1-\xi B)^{-1}(\xi/\Phi)\Lambda mrs_t, \tag{A6}$$

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

Next, we calculate RMC. By using (1), (4), (14), (15), and (A6), we obtain the following relationship between the marginal labor adjustment cost and labor gap under flexible prices:

$$\begin{aligned} & \ln\left[1+\frac{1}{W_t}E_t\sum_{k=0}^{\infty}\beta^k\left(\frac{\partial\Omega_{t+k}}{\partial L_t}\mid_{L_{t+k}=L^*_{t+k}\ \forall\ k}\right)\right] \\ = & \left[(\alpha-1)-(1-\xi\beta B^{-1})^{-1}(1-\xi B)^{-1}\frac{\xi\Lambda}{\Phi}(\alpha\sigma+\eta-1)\right]LGAP^*_t. \end{aligned} \quad \text{(A7)}$$

From (14), (23), and (A7), we obtain the following expression of RMC:

$$\begin{aligned} \ln RMC_t = & \ln\frac{1}{\alpha}+\ln S_t+\left[(\alpha-1)-(1-\xi\beta B^{-1})^{-1}(1-\xi B)^{-1}\frac{\xi\Lambda}{\Phi}(\alpha\sigma+\eta-1)\right] \\ & \left[(1+\gamma+\gamma\beta)LGAP^s_t-\gamma LGAP^s_{t-1}-\gamma\beta E_tLGAP^s_{t+1}\right]. \end{aligned} \quad \text{(A8)}$$

Combining (4), (6), and (A8), we derive the NKPC as follows:

$$\begin{aligned} \pi_t = & \beta E_t\pi_{t+1}+\frac{1}{\gamma}\ln\frac{\mu}{\alpha}+\frac{1}{\gamma}\ln S_t \\ & +\frac{1}{\gamma}\left[(\alpha-1)-(1-\xi\beta B^{-1})^{-1}(1-\xi B)^{-1}\frac{\xi\Lambda}{\Phi}(\alpha\sigma+\eta-1)\right] \\ & \left[(1+\gamma+\gamma\beta)LGAP^s_t-\gamma LGAP^s_{t-1}-\gamma\beta E_tLGAP^s_{t+1}\right]. \end{aligned} \quad \text{(A9)}$$

By using the VAR model that is introduced in Sections 4.1 and 4.2, we can express the closed-form solution of (A9) as follows:

$$\begin{aligned} \pi_t = & f_0+f_1e'_1(\mathbf{I}-\beta\mathbf{A})^{-1}\mathbf{Z}_t+f_2\left[f_1e'_2(\mathbf{I}-\beta\mathbf{A})^{-1}\mathbf{Z}_t+EDI_t-EDI_{t-1}\right] \\ & +f_3\sum_{h=1}^{\infty}\lambda^h\left[f_1e'_2(\mathbf{I}-\beta\mathbf{A})^{-1}\mathbf{Z}_{t-h}+(EDI_{t-h}-EDI_{t-h-1})\right] \\ & +f_3\sum_{j=1}^{\infty}(\lambda\beta)^je'_2\left[f_1\left((\mathbf{I}-\beta\mathbf{A})^{-1}-\sum_{l=1}^{j}\mathbf{A}^l\right)+(\mathbf{A}^j-\mathbf{A}^{j-1})\right]\mathbf{Z}_t, \end{aligned} \quad \text{(A10)}$$

where $f_0 = \frac{1}{\gamma(1-\beta)}\ln\frac{\mu}{\alpha}$, $f_1 = \frac{1}{\gamma}$, $f_2 = \delta\left[(\alpha-1)-\frac{\xi}{\Phi}\Lambda\frac{(\alpha\sigma+\eta-1)}{1-\xi^2\beta}\right]$, $f_3 = -\frac{\xi}{\Phi}\Lambda\frac{(\alpha\sigma+\eta-1)\delta}{1-\xi^2\beta}$.

The estimation results of (A10) 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 NKPC can explain the inflationary pressure around the bubble period. It implies that RMC is more pro-cyclical than labor share because of the existence of labor adjustment costs and real wage rigidity. This result is essentially the same as the result in Section 4.2.

Appendix B: Calculation of ζ_t[29]

The production technology of the representative firm is (33) and (34). Under this setup, the firm's total variable cost is

$$W_t L_t + P_{M,t} M_t = W_t (Q_t/A_t)^{1/\alpha} + P_{M,t} m(Q_t) Q_t. \tag{B1}$$

The nominal marginal cost on gross output ($MC_{Q,t}$) is calculated as follows:

$$MC_{Q,t} = \frac{\partial (W_t (Q_t/A_t)^{1/\alpha})}{\partial Q_t} + P_{M,t}(m'(Q_t)Q_t + m(Q_t)). \tag{B2}$$

Since (33) implies $Q_t = Y_t$, (A2) is rewritten as

$$MC_{Q,t} = \frac{1}{\alpha}\frac{W_t L_t}{Q_t} + P_{M,t} m(Q_t)\varepsilon_m + P_{M,t} m(Q_t), \tag{B3}$$

where $\varepsilon_m \equiv \frac{m'(Q_t)Q_t}{m(Q_t)}$. From the identity,

$$P_{Q,t} Q_t - P_t Y_t = P_{M,t} m(Q_t) Q_t. \tag{B4}$$

The profit generated by producing an extra unit of output is

$$P_{Q,t} - MC_{Q,t} = P_t - MC_t. \tag{B5}$$

From (A4), (A5), and $Q_t = Y_t$, we can calculate RMC on value added ($RMC_t = \frac{MC_t}{P_t}$) as follows:

$$RMC_t = \frac{1}{\alpha} S_t + \zeta_t, \tag{B6}$$

where ζ_t is calculated as (35).

[29] This appendix closely follows Batini, Jackson, and Nickell [2000].

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Table 1: NKPC with Labor Share

	VAR specifications			
	$\begin{bmatrix} lnS_t \end{bmatrix}$	$\begin{pmatrix} lnS_t \\ \Delta ULC_t \end{pmatrix}$	$\begin{pmatrix} lnS_t \\ \pi_t \end{pmatrix}$	$\begin{pmatrix} lnS_t \\ \Delta ULC_t \\ \pi_t \end{pmatrix}$
a_0	0.186	0.317	0.240	0.390
t-value	(4.42)	(3.87)	(5.79)	(5.12)
a_1	0.004	0.008	0.006	0.009
t-value	(4.33)	(3.82)	(5.70)	(5.07)
Adj-R^2	0.130	0.103	0.209	0.172
D.W.	*0.823*	*0.828*	*0.861*	*0.844*
VAR lags	2	1	2	1

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 RMC: Including Labor Adjustment Costs
(Without Real Wage Rigidity)

	VAR specifications			
	$\begin{pmatrix} \ln S_t \\ EDI_t \end{pmatrix}$	$\begin{pmatrix} \ln S_t \\ EDI_t \\ \Delta ULC_t \end{pmatrix}$	$\begin{pmatrix} \ln S_t \\ EDI_t \\ \pi_t \end{pmatrix}$	$\begin{pmatrix} \ln S_t \\ EDI_t \\ \Delta ULC_t \\ \pi_t \end{pmatrix}$
b_0	0.382	0.374	0.394	0.374
t-value	(6.83)	(6.67)	(7.38)	(7.13)
b_1	0.009	0.009	0.009	0.009
t-value	(6.75)	(6.59)	(7.30)	(7.05)
b_2	-0.032	-0.033	-0.035	-0.035
t-value	(-2.56)	(-2.59)	(-2.85)	(-2.75)
$Adj\text{-}R^2$	0.286	0.275	0.319	0.303
D.W.	1.135	1.123	1.117	1.101
VAR lags	2	2	2	2

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

Table 3: NKPC with RMC: Including Labor Adjustment Costs
(With Real Wage Rigidity)

	VAR specifications			
	$\begin{pmatrix} \ln S_t \\ EDI_t \end{pmatrix}$	$\begin{pmatrix} \ln S_t \\ EDI_t \\ \Delta ULC_t \end{pmatrix}$	$\begin{pmatrix} \ln S_t \\ EDI_t \\ \pi_t \end{pmatrix}$	$\begin{pmatrix} \ln S_t \\ EDI_t \\ \Delta ULC_t \\ \pi_t \end{pmatrix}$
c_0	0.382	0.373	0.456	0.433
t-value	(5.83)	(5.71)	(6.87)	(6.59)
c_1	0.009	0.009	0.011	0.010
t-value	(5.78)	(5.66)	(6.82)	(6.54)
c_2	-0.008	-0.008	-0.014	-0.014
t-value	(-0.52)	(-0.57)	(-0.99)	(-0.98)
c_3	-0.016	-0.016	-0.017	-0.017
t-value	(-2.58)	(-2.56)	(-2.98)	(-2.93)
ρ	0.939	0.941	0.940	0.943
t-value	(11.83)	(11.78)	(13.75)	(13.59)
Adj-R^2	0.328	0.319	0.391	0.374
D.W.	1.492	1.480	1.547	1.527
VAR lags	2	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 4: Elasticity of Material/Output Ratio to Gross 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 5: NKPC with RMC: Including Labor Adjustment Costs and Material Prices (With Real Wage Rigidity)

	VAR specifications			
	$\begin{pmatrix} ln\,(S_t+\zeta_t) \\ EDI_t \end{pmatrix}$	$\begin{pmatrix} ln\,(S_t+\zeta_t) \\ EDI_t \\ \Delta\,ULC_t \end{pmatrix}$	$\begin{pmatrix} ln\,(S_t+\zeta_t) \\ EDI_t \\ \pi_t \end{pmatrix}$	$\begin{pmatrix} ln\,(S_t+\zeta_t) \\ EDI_t \\ \Delta\,ULC_t \\ \pi_t \end{pmatrix}$
d_0	0.084	0.081	0.086	0.083
t-value	(9.28)	(9.04)	(9.33)	(9.06)
d_1	0.003	0.003	0.004	0.003
t-value	(8.97)	(8.72)	(9.02)	(8.75)
d_2	0.008	0.008	0.007	0.007
t-value	(0.60)	(0.56)	(0.55)	(0.52)
d_3	-0.013	-0.013	-0.013	-0.013
t-value	(-2.44)	(-2.44)	(-2.46)	(-2.46)
ρ	0.958	0.961	0.961	0.963
t-value	(11.54)	(11.62)	(11.72)	(11.78)
Adj-R^2	0.490	0.477	0.494	0.480
D.W.	*1.870*	*1.835*	*1.857*	*1.829*
VAR lags	2	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 6: Hybrid NKPC with Labor Share

	VAR specifications			
	$\begin{bmatrix} lnS_t \end{bmatrix}$	$\begin{pmatrix} lnS_t \\ \Delta ULC_t \end{pmatrix}$	$\begin{pmatrix} lnS_t \\ \pi_t \end{pmatrix}$	$\begin{pmatrix} lnS_t \\ \Delta ULC_t \\ \pi_t \end{pmatrix}$
a_0	0.082	0.129	0.124	0.198
t-value	(2.12)	(1.75)	(3.02)	(2.75)
a_1	0.002	0.003	0.003	0.005
t-value	(2.09)	(1.73)	(2.98)	(2.73)
inflation lag	0.506	0.520	0.461	0.483
t-value	(6.82)	(7.06)	(6.10)	(6.53)
$Adj\text{-}R^2$	0.372	0.365	0.395	0.388
D.W.	*2.128*	*2.155*	*2.057*	*2.089*
VAR lags	2	1	2	1

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 7: Hybrid NKPC with RMC: Including Labor Adjustment Costs (Without Real Wage Rigidity)

	VAR specifications			
	$\begin{pmatrix} \ln S_t \\ EDI_t \end{pmatrix}$	$\begin{pmatrix} \ln S_t \\ EDI_t \\ \Delta ULC_t \end{pmatrix}$	$\begin{pmatrix} \ln S_t \\ EDI_t \\ \pi_t \end{pmatrix}$	$\begin{pmatrix} \ln S_t \\ EDI_t \\ \Delta ULC_t \\ \pi_t \end{pmatrix}$
b_0	0.207	0.199	0.226	0.209
t-value	(3.67)	(3.57)	(4.12)	(3.95)
b_1	0.005	0.005	0.005	0.005
t-value	(3.64)	(3.54)	(4.09)	(3.92)
b_2	-0.025	-0.025	-0.027	-0.026
t-value	(-2.05)	(-2.04)	(-2.24)	(-2.16)
inflation lag	0.416	0.425	0.393	0.405
t-value	(5.31)	(5.45)	(5.04)	(5.21)
$Adj\text{-}R^2$	0.419	0.416	0.435	0.428
D.W.	2.159	2.167	2.105	2.121
VAR lags	2	2	2	2

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

Table 8: Hybrid NKPC with RMC: Including Labor Adjustment Costs (With Real Wage Rigidity)

	VAR specifications			
	$\begin{pmatrix} \ln S_t \\ EDI_t \end{pmatrix}$	$\begin{pmatrix} \ln S_t \\ EDI_t \\ \Delta ULC_t \end{pmatrix}$	$\begin{pmatrix} \ln S_t \\ EDI_t \\ \pi_t \end{pmatrix}$	$\begin{pmatrix} \ln S_t \\ EDI_t \\ \Delta ULC_t \\ \pi_t \end{pmatrix}$
c_0	0.251	0.241	0.332	0.305
t-value	(3.67)	(3.56)	(4.53)	(4.27)
c_1	0.006	0.006	0.008	0.007
t-value	(3.64)	(3.53)	(4.50)	(4.24)
c_2	0.001	0.001	-0.005	-0.004
t-value	(0.10)	(0.09)	(-0.35)	(-0.30)
c_3	-0.014	-0.014	-0.016	-0.015
t-value	(-2.21)	(-2.18)	(-2.61)	(-2.53)
ρ	0.908	0.908	0.923	0.924
t-value	(9.23)	(9.13)	(11.49)	(11.16)
inflation lag	0.305	0.313	0.241	0.257
t-value	(3.41)	(3.50)	(2.73)	(2.88)
Adj-R^2	0.389	0.384	0.424	0.412
D.W.	2.257	2.260	2.143	2.159
VAR lags	2	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 9: Hybrid NKPC with RMC: Including Labor Adjustment Costs and Material Prices (With Real Wage Rigidity)

	VAR specifications			
	$\begin{pmatrix} ln(S_t+\zeta_t) \\ EDI_t \end{pmatrix}$	$\begin{pmatrix} ln(S_t+\zeta_t) \\ EDI_t \\ \Delta ULC_t \end{pmatrix}$	$\begin{pmatrix} ln(S_t+\zeta_t) \\ EDI_t \\ \pi_t \end{pmatrix}$	$\begin{pmatrix} ln(S_t+\zeta_t) \\ EDI_t \\ \Delta ULC_t \\ \pi_t \end{pmatrix}$
d_0	0.076	0.071	0.078	0.073
t-value	(6.14)	(5.91)	(6.20)	(5.94)
d_1	0.003	0.003	0.003	0.003
t-value	(6.01)	(5.78)	(6.07)	(5.81)
d_2	0.009	0.009	0.009	0.009
t-value	(0.69)	(0.68)	(0.64)	(0.64)
d_3	-0.013	-0.013	-0.013	-0.013
t-value	(-2.29)	(-2.26)	(-2.31)	(-2.28)
ρ	0.944	0.944	0.948	0.948
t-value	(10.36)	(10.21)	(10.54)	(10.39)
inflation lag	0.088	0.108	0.087	0.105
t-value	(0.92)	(1.13)	(0.92)	(1.10)
Adj-R^2	0.489	0.478	0.493	0.481
D.W.	*2.070*	*2.081*	*2.057*	*2.069*
VAR lags	2	2	2	2

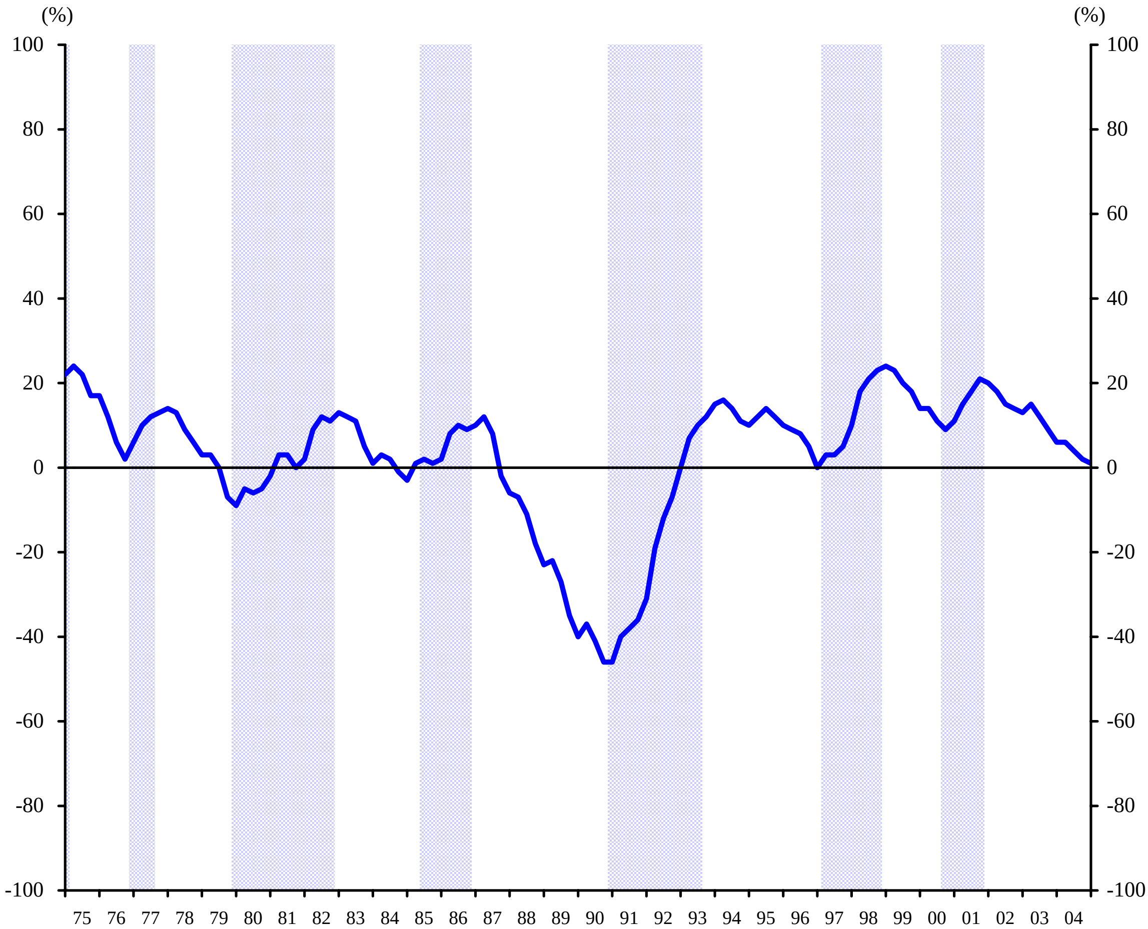
Note: The dependent variable is the GDP deflator (non-annualized). The estimation method is NLS. The sample period is 1977/Q3-2004/Q4. VAR lags are chosen by Schwarz's information criterion.

Appendix Table: NKPC with RMC: Including Labor Adjustment Costs
(With Model of Staggered Real Wage Setting)

	VAR specifications			
	$\begin{pmatrix} \ln S_t \\ EDI_t \end{pmatrix}$	$\begin{pmatrix} \ln S_t \\ EDI_t \\ \Delta ULC_t \end{pmatrix}$	$\begin{pmatrix} \ln S_t \\ EDI_t \\ \pi_t \end{pmatrix}$	$\begin{pmatrix} \ln S_t \\ EDI_t \\ \Delta ULC_t \\ \pi_t \end{pmatrix}$
f_0	0.664	0.669	0.860	0.837
t-value	(7.53)	(7.84)	(10.22)	(10.16)
f_1	0.016	0.016	0.020	0.020
t-value	(7.48)	(7.79)	(10.17)	(10.11)
f_2	0.000	0.006	0.012	0.014
t-value	(-0.02)	(0.32)	(0.72)	(0.86)
f_3	-0.018	-0.021	-0.026	-0.027
t-value	(-2.83)	(-3.15)	(-4.35)	(-4.48)
λ	0.909	0.878	0.851	0.841
t-value	(12.48)	(12.77)	(16.59)	(16.66)
$Adj\text{-}R^2$	0.287	0.302	0.427	0.425
D.W.	1.463	1.487	1.534	1.522
VAR lags	2	2	2	2

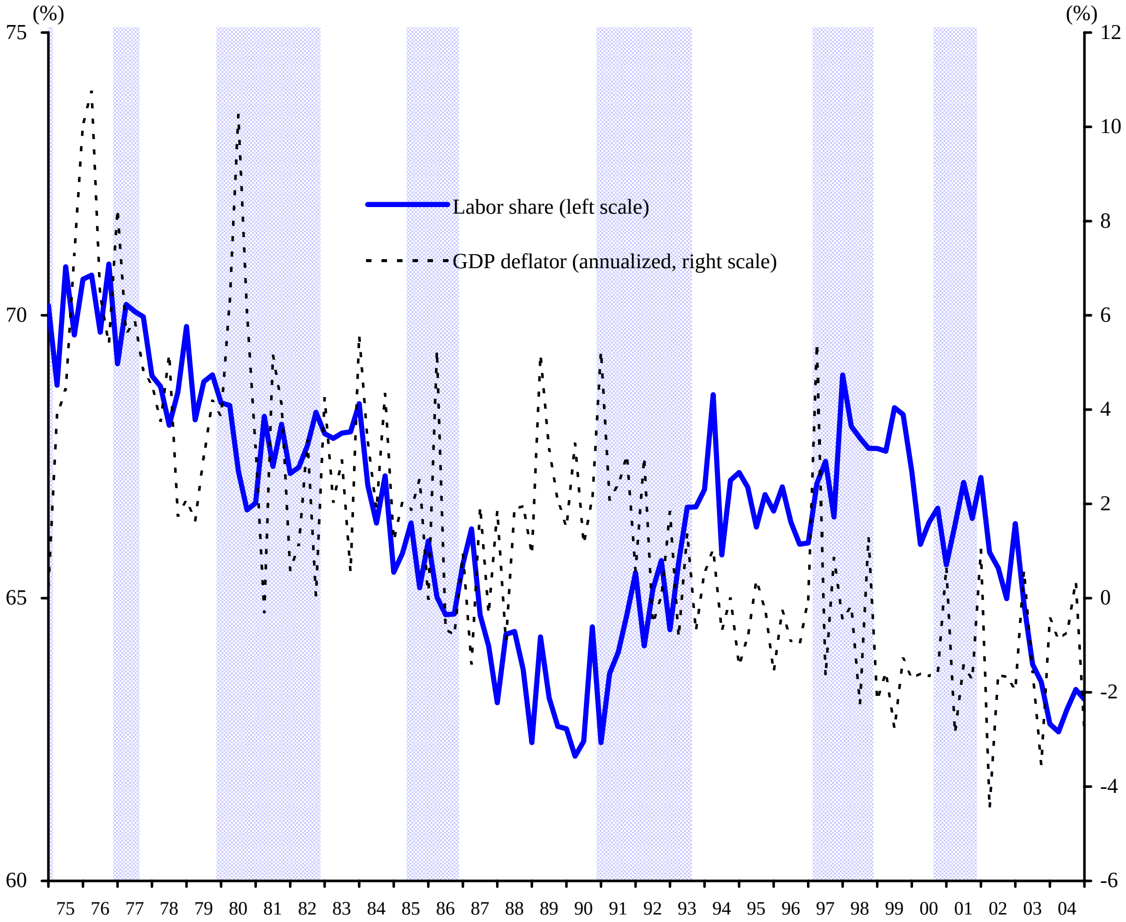
Note: The dependent variable is the GDP deflator (non-annualized). The estimation method is NLS. The sample period is 1977/Q3-2004/Q4. VAR lags are chosen by Schwarz's information criterion.

Figure 1: Labor Gap in Japan



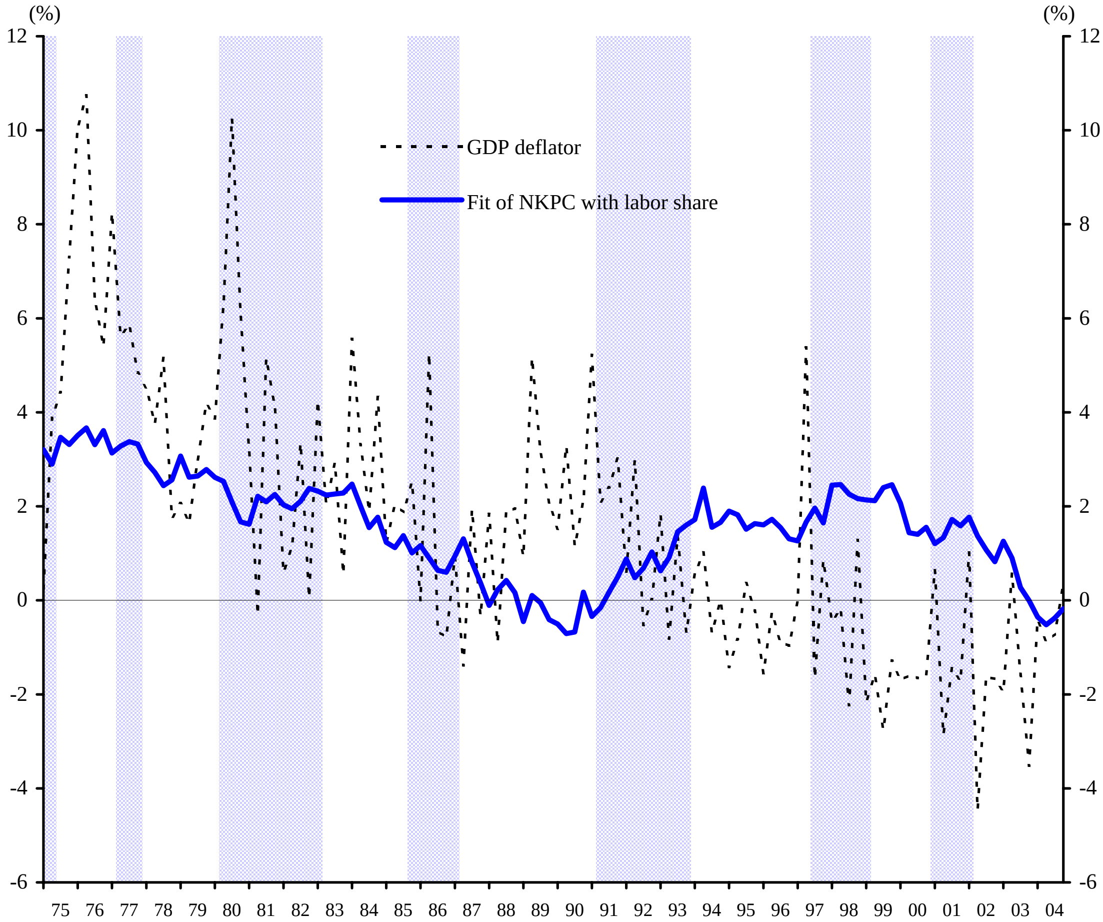
Note: The figure shows the employment DI in the Bank of Japan's *Tankan* survey. Shaded areas indicate recession dates.

Figure 2: Labor Share and Inflation Rate in Japan



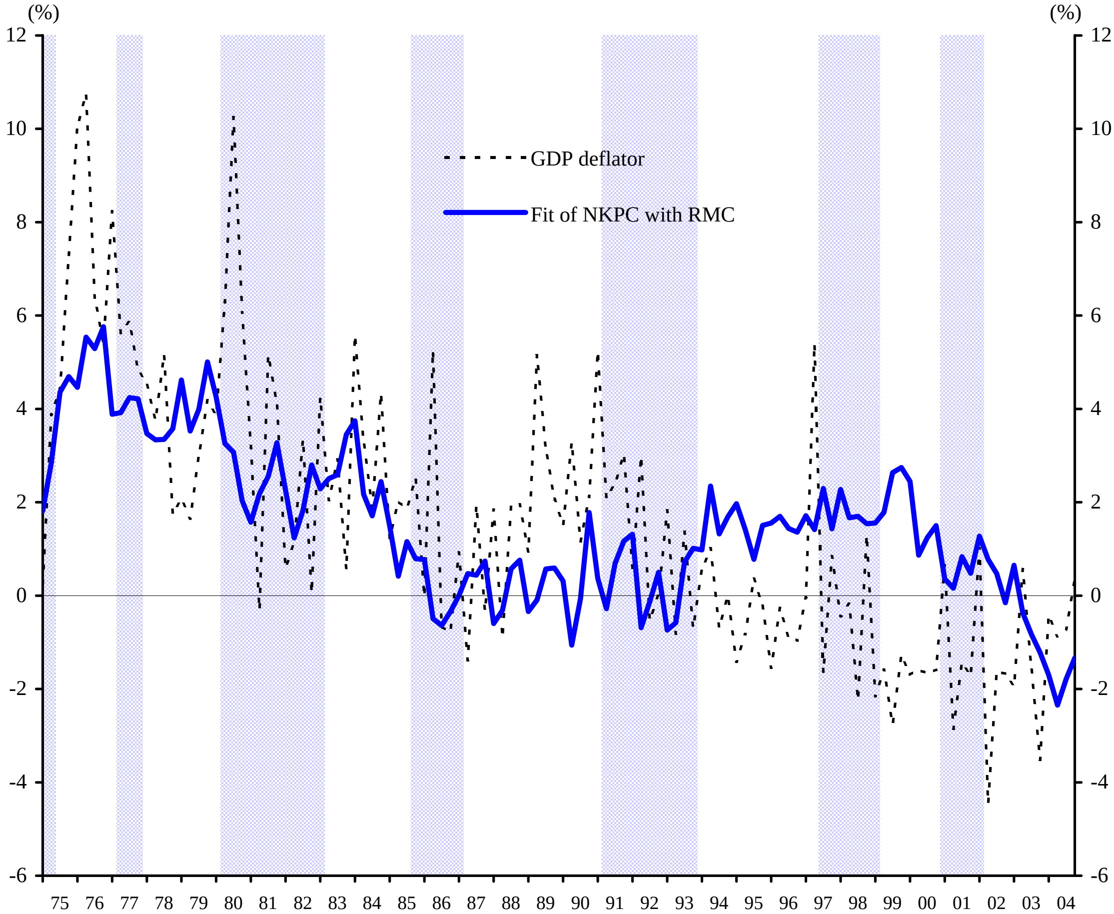
Note: Shaded areas indicate recession dates.

Figure 3: NKPC with Labor Share



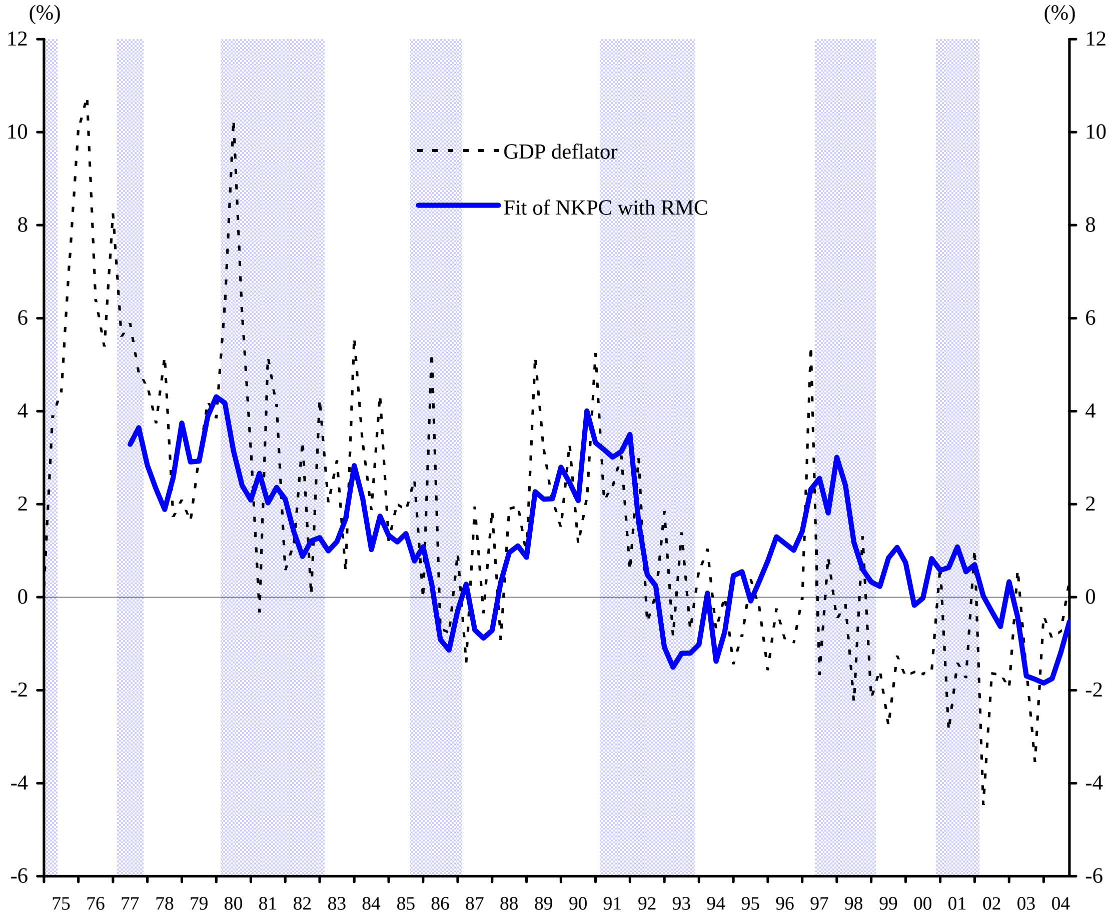
Note: The NKPC is based on the auxiliary VAR that includes only lnS_t. Shaded areas indicate recession dates.

Figure 4: NKPC with RMC: Including Labor Adjustment Costs
(Without Real Wage Rigidity)



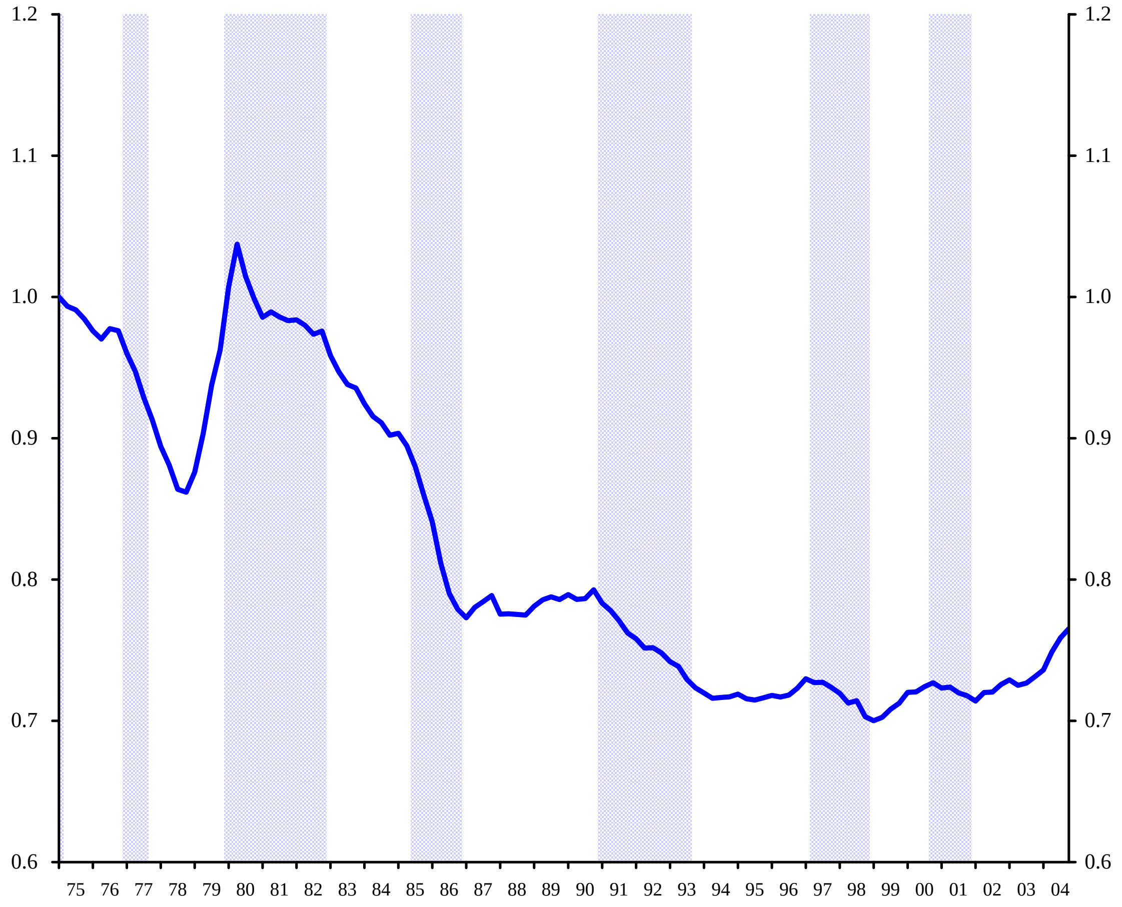
Note: The NKPC is based on the auxiliary VAR that includes lnS_t and EDI_t. Shaded areas indicate recession dates.

Figure 5: NKPC with RMC: Including Labor Adjustment Costs (With Real Wage Rigidity)



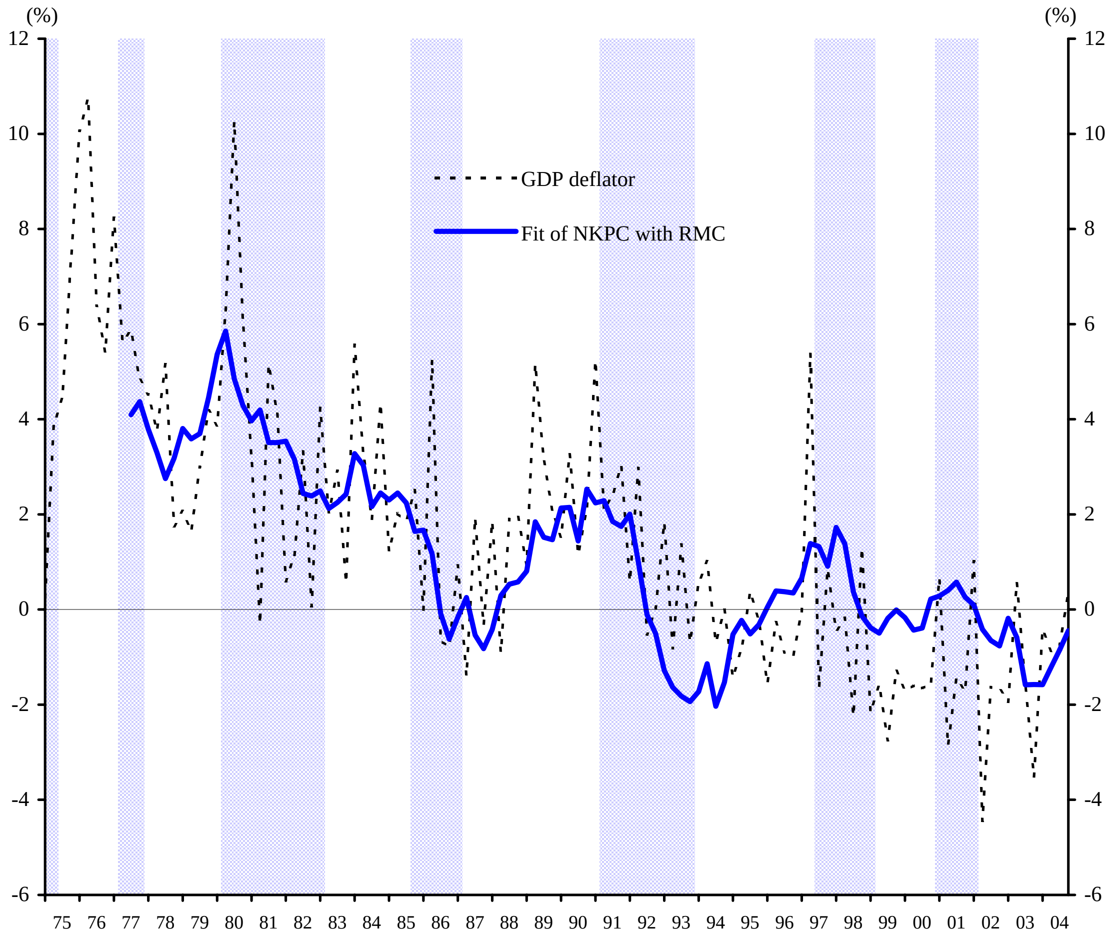
Note: The NKPC is based on the auxiliary VAR that includes lnS_t and EDI_t. Shaded areas indicate recession dates.

Figure 6: Relative Price of Material to Value-Added



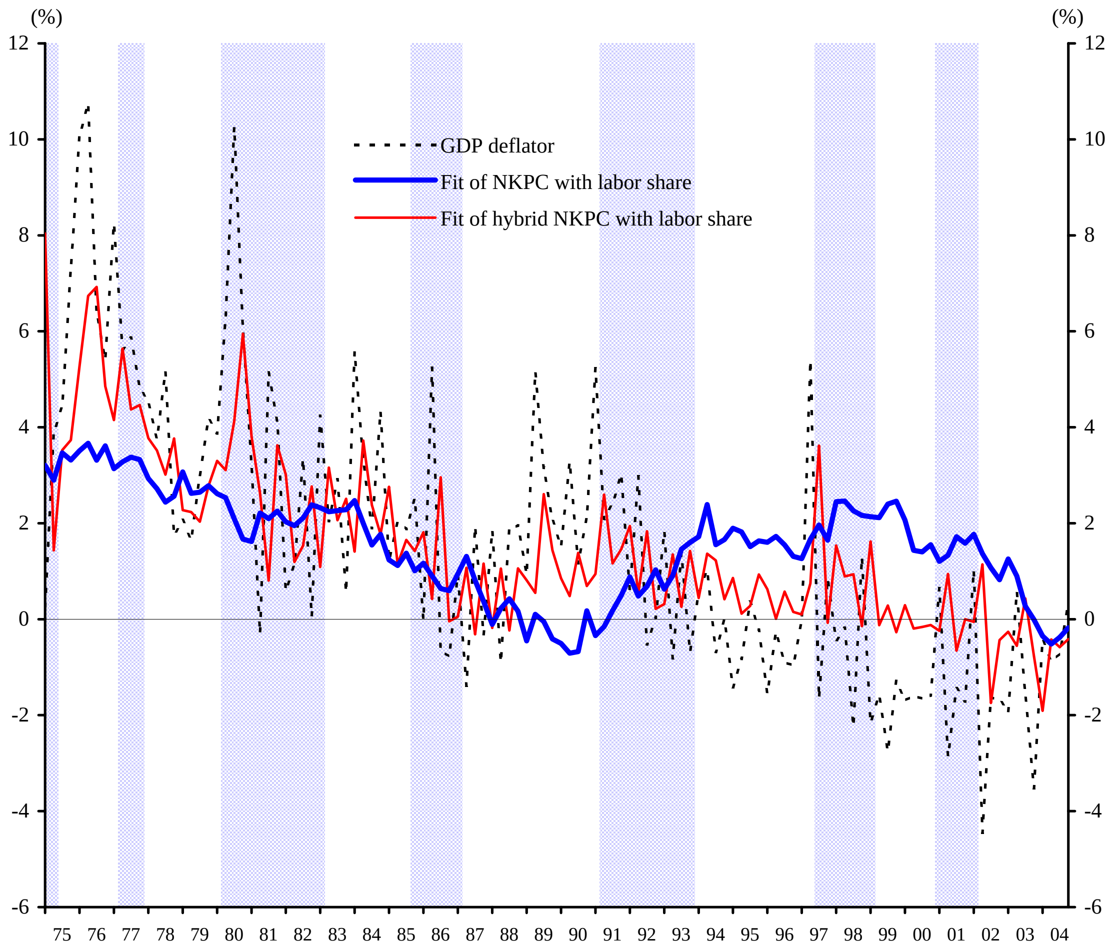
Note: The level in 1975Q1 is normalized as unity. Shaded areas indicate recession dates.

Figure 7: NKPC with RMC: Including Labor Adjustment Costs and Material Prices (With Real Wage Rigidity)



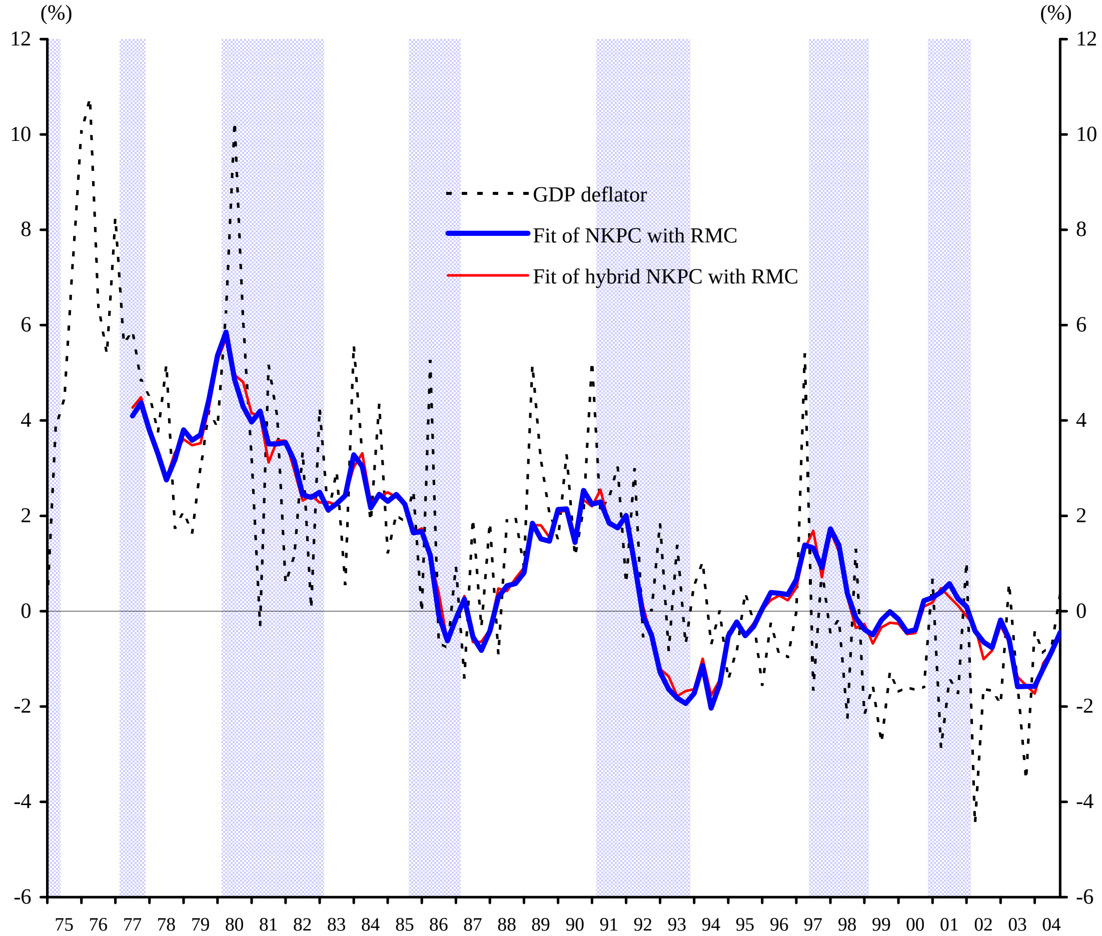
Note: The NKPC is based on the auxiliary VAR that includes $ln\,(S_t+\zeta_t)$ and EDI_t. Shaded areas indicate recession dates.

Figure 8: "Hybrid" NKPC with Labor Share



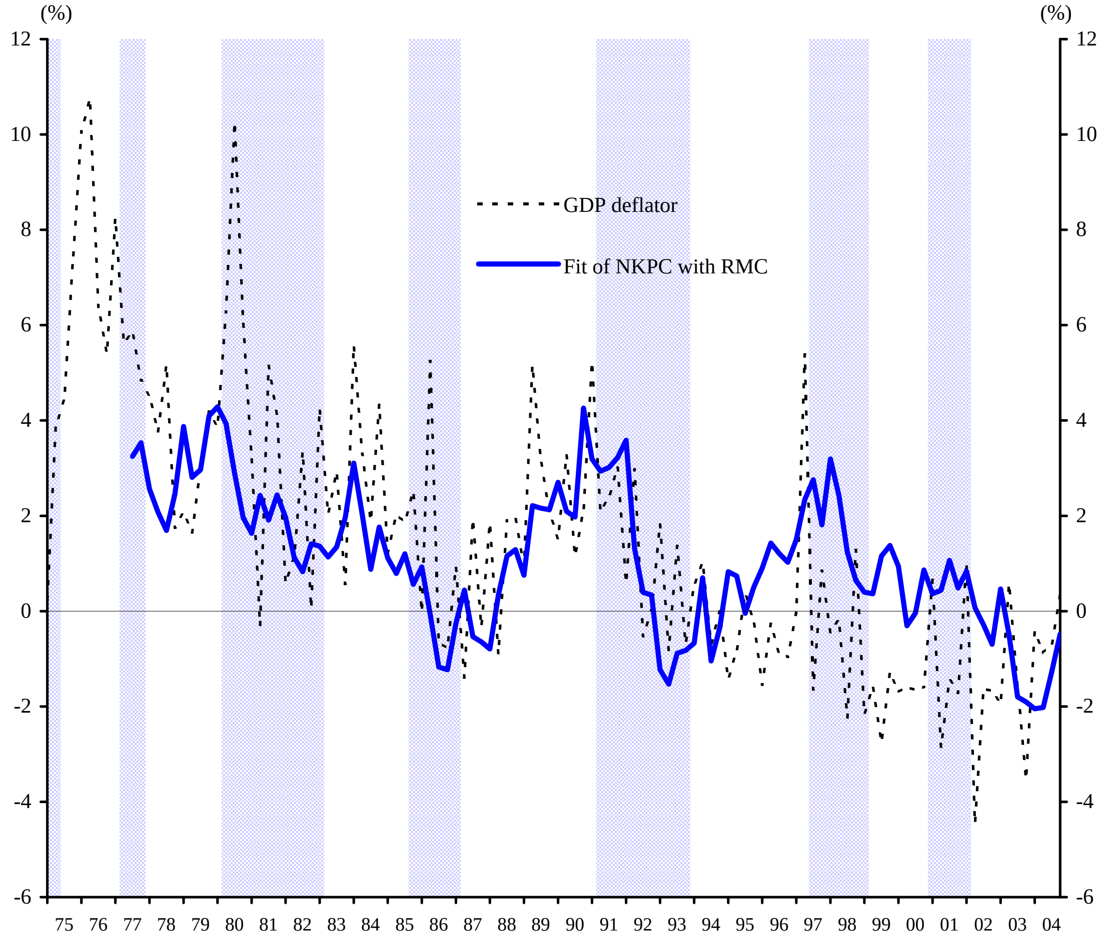
Note: The NKPC is based on the auxiliary VAR that includes only lnS_t. Shaded areas indicate recession dates.

Figure 9: "Hybrid" NKPC with RMC: Including Labor Adjustment Costs and Material Prices (With Real Wage Rigidity)



Note: The NKPC is based on the auxiliary VAR that includes $ln\,(S_t + \zeta_t)$ and EDI_t. Shaded areas indicate recession dates.

Appendix Figure: NKPC with RMC: Including Labor Adjustment Costs (With Model of Staggered Real Wage Setting)



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