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ABSTRACT

This paper demonstrates the time-varying NAIRU approach for estimation of the potential rate of growth, where the latter is defined as the growth rate at which the inflation rate would be neither accelerating nor decelerating. We show theoretically that this inflation-neutral potential rate of growth is determined by three factors: the rate of technological progress, the growth rates of the production factors, and the shift in the NAIRU. We conduct empirical analysis for Japan since the latter half of the 1980s and show that all three factors have contributed to the lowering of the Japanese potential rate of growth since the early 1990s. In particular, we discover that it was the shift in the NAIRU that caused the protracted period of slowdown in Japanese potential growth around the midst of the 1990s. Furthermore, we show that since 2000, with the strengthening of East Asian international competitiveness, Japan has been driven to substantial reform of its old economic structure, and this may have brought about an acceleration of the shift in the NAIRU. We also point out that the NAIRU estimate and its relationship with the inflation rate are subject to various kinds of uncertainty, and thus care should be taken in their evaluation and interpretation.

(*JFL classification: E3, N1, O1*; keywords: output gap, potential growth, NAIRU)

I. INTRODUCTION

Since the bursting of the asset bubble in the early 1990s, the Japanese economy suffered a prolonged period of stagnation, and in fiscal 2001 the annual growth rate of real GDP was –1.9 percent (Chart 1). With regard to price movements, Japan has been under stubborn deflationary pressure whose roots can be traced to the long-lasting stagnation of economic activity, the intensified international competition from East Asia, and the deregulation that continues throughout the country. Nonetheless, when we look closely at the relationship between price movements and the behavior of real GDP, we find that the Japanese economy often appears to have been saved from the more serious deflation that might have been anticipated, given its deepening economic deterioration. In contrast, the United States experienced high growth rates of more than 4 percent and nonetheless enjoyed a low inflation rate during the latter half of the 1990s.

These observations for Japan and the US represent an important issue that challenges our understanding of the relationship between price movements and real activity. From the Phillips curve point of view, the reason that the slowdown of actual economic growth failed to exacerbate deflation is that there occurred a simultaneous slowdown of potential growth.[1] Various factors may have induced this stagnation in potential growth. First, there was a deceleration in the rate of technological progress due to a reduction in R&D activity, where the latter can, in turn, ultimately be traced back to the stagnant economic activity. Second, there was a slowdown in the growth rates of the production factors, as observed in the declining pace of capital accumulation. Third, it is possible that the "normal" rate of capacity utilization declined for each production factor.

With regard to the third point above, some further explanation is appropriate here. We can show that the output gap (i.e., the gap between aggregate demand and supply in

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[1] See, for example, Watanabe (1997), Higo and Nakada (2000), and Bank of Japan Research and Statistics Department (2000) for the estimation of the Japanese Phillips curve. Fuhrer (1995) discusses the stability of the US Phillip curve. High US growth triggered the discussion about the "New Economy," which claims that US growth is supported by the "IT revolution."

the economy, defined precisely in Section II) is given by the average unemployment rate across all factors of production. Analogous to the natural unemployment rate, or the NAIRU (*N*on-*A*ccelerating *I*nflation *R*ate of *U*nemployment), there exists a “normal” rate for the gap between aggregate demand and supply. We call this normal rate of the demand-supply gap the NAIRU in a broad sense on the understanding that inflationary pressure stems from the divergence of actual GDP from the NAIRU. According to this idea, one of the reasons that deflation failed to decelerate in spite of the slowdown of economic activity is that there was also a slowdown in the potential rate of growth due to declines in the NAIRU.

As argued by Friedman (1968), it has long been recognized that the NAIRU may vary for a variety of reasons, and this idea has recently been receiving renewed attention from the viewpoint of monetary policy and price stability.[2,3] We think that the time-varying NAIRU provide a useful framework for understanding price developments in Japan. For instance, even when the output gap widens, the resulting deflationary pressure will be eliminated if there is a decline in the NAIRU. For example, international competitive pressure from East Asia drove the Japanese economy to make significant changes in its economic structure. This created a mismatch in the labor market, which may in turn have induced a shift in the NAIRU level. In addition, it is not rare for young people today to postpone taking jobs until a favorable option comes up. This type of new trend in attitudes of younger generations toward their professions has induced shifts in the NAIRU. The purpose of this paper is to show to what extent such shifts in the time-varying NAIRU have affected potential Japanese growth and to make use of this information to understand price developments in Japan.

The remainder of this paper is constructed as follows. In Section II, we present the basic concepts used frequently in this paper, such as potential output, the output gap, and the NAIRU, and summarize the relationships among them. We also briefly explain the technique for estimation of the time-varying NAIRU. In Section III, we

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[2] Friedman (1968) lists the factors that affect the NAIRU in the US: the existence of legal minimum wage, the strength of labor unions, improvements in employment exchanges, availability of information about job vacancies and labor supply.

[3] *Journal of Economic Perspectives* (winter 1997) features a number of articles on the NAIRU.

estimate the time-varying NAIRU for Japan. Based on the estimated NAIRU, we also estimate the potential rate of growth in Japan. In Section IV, we list caveats that should be borne in mind when evaluating the estimation results. Finally, in Section V, we conclude with a summary of our arguments in this paper.

II. Model

In this section, we discuss the following two issues through the medium of simple mathematical formulas. First, we explain the reason that information on the NAIRU is necessary to estimate the potential rate of growth. Second, we demonstrate how to estimate the NAIRU, which is not directly observable.

A. Basic Concepts: Potential Output, the Output Gap, and the NAIRU

We start by defining the three key words used frequently in the paper: *potential output*, the *output gap*, and the *NAIRU*. There are two separate concepts of potential output that should be distinguished from each other. First, suppose that all available production factors, such as labor and capital, are fully utilized. We can call the full-employment output obtained in this situation the *maximal output* and denote it by Y^* below. The deviation rate of actual output, Y, from this maximal output is called the output gap, denoted by G. One example is Kamada and Masuda's (2001) output gap that takes capacity utilization in the non-manufacturing sector into consideration.

$$G \equiv \ln Y - \ln Y^* . \qquad (2\text{-}1)$$

The second concept of potential output describes the level of output at which the inflation rate would be neither accelerating nor decelerating. We call this the *inflation-neutral output* and denote it by Y^N. The deviation rate of the inflation-neutral output from actual output is called the *NAIRU*, denoted by G^N.

$$G^N \equiv \ln Y^N - \ln Y^* . \qquad (2\text{-}2)$$

Put differently, the NAIRU is the output gap consistent with a non-accelerating inflation rate. Notice that the following relationship holds between output levels and output gaps:

$$G - G^N = \ln Y - \ln Y^N \,. \qquad (2\text{-}3)$$

A macro production function provides a bridge between the output gap concepts and the capacity utilization rates of the production factors. Consider the following Cob-Douglas type production function.

$$Y = A \cdot L^{\alpha} \cdot (\gamma \cdot K)^{1-\alpha} \,. \qquad (2\text{-}4)$$

where A is total factor productivity (TFP); α the labor share; L hours worked; K the capital stock; and γ capacity utilization of the capital stock. Denote the maximal amount of working hours by L^*. We can then define the capacity utilization rate of labor force as $\eta = L / L^*$. Substituting these figures into the production function and taking the log of the result, we obtain

$$\ln Y = \ln A + \{\alpha \cdot \ln \eta + (1-\alpha) \cdot \ln \gamma\} + \{\alpha \cdot \ln L^* + (1-\alpha) \cdot \ln K\} \,. \qquad (2\text{-}5)$$

Assuming $\eta = 1$ and $\gamma = 1$, we obtain the maximal output as follows:

$$\ln Y^* = \ln A + \{\alpha \cdot \ln L^* + (1-\alpha) \cdot \ln K\} \,. \qquad (2\text{-}6)$$

Hence, the output gap ($\equiv \ln Y - \ln Y^*$) is given by

$$G = \alpha \cdot \ln \eta + (1-\alpha) \cdot \ln \gamma \,. \qquad (2\text{-}7)$$

Call the production-factor capacity utilization rates that sustain the inflation-neutral output the *inflation-neutral capacity utilization rates*. The inflation-neutral capacity utilization rates of labor and capital (η^N, γ^N) can then be defined implicitly as

$$G^N \equiv \alpha \cdot \ln \eta^N + (1-\alpha) \cdot \ln \gamma^N \,. \qquad (2\text{-}8)$$

It is impossible to determine the inflation-neutral capacity utilization rates of the two production factors from equation (2-8) alone. In this regard, Appendix A introduces “Okun’s Law,” which posits a strong relationship between the unemployment rate and the output gap, and reexamines the model in the light of this. Appendix B then argues how an additional assumption allows us to disentangle the two inflation-neutral capacity utilization rates from the one inflation-neutral output gap.

Next, we consider the inflation-neutral potential rate of growth. Taking first differences of equation (2-2), we obtain

$$\hat{Y}^N = \hat{Y}^* + \Delta G^N \tag{2-9}$$

$$= \hat{A} + \{\alpha \cdot \hat{L}^* + (1-\alpha)\cdot \hat{K}\} + \Delta G^N . \tag{2-10}$$

where the notation $\hat{X}$ is used to describe the growth rate of variable X. To obtain equation (2-10), we make use of the first difference of equation (2-6). This equation states that the inflation-neutral potential rate of growth consists of (i) the rate of technological progress, (ii) the growth rates of the production factors, and (iii) the shift in the NAIRU.[4]

B. Estimation Method for the Time-Varying NAIRU

Of the three factors discussed above as determinants of the inflation-neutral potential rate of growth, our interest in this paper is confined to introducing a method for estimating a shift in the NAIRU. Please refer to Kamada and Masuda (2001) for details regarding estimation of the rate of technological progress and the growth rates of the production factors.

The NAIRU describes the output gap at which the inflation rate would be neither accelerating nor decelerating. This implies that G^N occupies the following position in the Phillips curve:

$$\pi_t = \pi_t^e + \beta \cdot (G_t - G_t^N) + \varepsilon_t . \tag{2-11}$$

where π is the inflation rate, and π^e the expected rate of inflation. In the empirical

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[4] Another formula to calculate the inflation-neutral potential rate of growth is

$$\hat{Y}^N = \hat{Y} - \Delta G + \Delta G^N .$$

Equation (2-7) says that we can estimate the output gap with data on capacity utilization rates of capital and labor. With information on changes in the NAIRU, therefore, we no longer need to use any capital stock statistics to estimate the inflation-neutral potential rate of growth. The single exception is the use of capital stock data as weights in averaging capacity utilization rates of capital in manufacturing and non-manufacturing sectors.

literature, we often describe the expected rate of inflation as a moving average of past inflation rates.

$$\pi_t^e = \Sigma_{i=1}^{q}(\alpha_i \cdot \pi_{t-i}), \quad \Sigma_{i=1}^{q}\alpha_i = 1. \tag{2-12}$$

As we cannot observe G^N directly, we model its behavior as a random walk.

$$G_t^N = G_{t-1}^N + \nu_t. \tag{2-13}$$

We can construct a state-space model by thinking of G^N as a state variable, equation (2-11) as an observation equation, and equation (2-13) as a transition equation, and we use the Kalman filter to estimate G^N, α_i, and β simultaneously.

III. RESULTS

In this section, based on the Japanese data, we estimate the NAIRU (both the time-invariant and the time-varying types) and the inflation-neutral potential rate of growth. We have two reasons for estimating the time-invariant NAIRU. First, we are keen to demonstrate the deficiencies of the time-invariant NAIRU when it comes to describe price developments in Japan from the 1990s onward, thereby illustrating the need to estimate the time-varying NAIRU. Second, we also wish to use the time-invariant NAIRU as an initial value in estimating the time-varying NAIRU using the Kalman filter. Once we obtain the time-varying NAIRU, it is easy to estimate the inflation-neutral potential rate of growth and use this information to find to what extent the shift in the NAIRU contributed to the slowing of the potential rate of growth in Japan.

A. Estimation of the Time-Invariant NAIRU

Before estimating the time-varying NAIRU, we calculate the time-invariant NAIRU and evaluate the estimation results. We can consider the time-invariant NAIRU as a special case of the time-varying NAIRU where the variance of the innovation (ν) is zero. We may then treat G^N as a constant term, thus enabling us to use OLS to estimate the time-invariant NAIRU.

To save coefficients to be estimated, we specify the structure of the expected rate of inflation as a weighted average of two moving averages and estimate the weights. Later, we use the same specification in estimating the time-varying NAIRU.

$$\pi_t^e = \alpha \cdot \Sigma_{i=1}^{4} \pi_{t-i} / 4 + (1-\alpha) \cdot \Sigma_{i=5}^{8} \pi_{t-i} / 4 . \qquad (3\text{-}1)$$

We treat import prices as a representative supply side shock and add these into the Phillips curve as another explanatory variable. More precisely, we use the deviation of the current rate of change in import prices from the moving average of the past four quarters.

We use the following Japanese data: the inflation rate from the seasonally adjusted CPI (excluding fresh food and adjusted for consumption taxes on an annualized quarter-to-quarter percentage basis) and the output gap introduced by Kamada and Masuda (2001), which takes into account the capacity utilization rate in the non-manufacturing sector. The sample ranges from the second quarter of 1983 to the second quarter of 2002. The estimation results are summarized in Chart 2(1). The explanatory variables in the Phillips curve are all significant and take the signs suggested by theory. The R^2 is 71%, showing that the Phillips curve fits the Japanese data reasonably well. In particular, the sign of the coefficient β on the output gap is positive and significant. This is important since the sign ensures the existence of the Phillips curve relationship in Japan. The time-invariant NAIRU is estimated to be –4.7 percent.

B. Estimation of the Time-Varying NAIRU

Next, we estimate the time-varying NAIRU using the Kalman filter. There are two practical issues that emerge when we employ the Kalman filter. Since the estimation results may often depend on the initial values chosen for the state variable (the NAIRU here) and for the constant parameters, the first question is how to choose these initial values. Remember that we are discussing the advantage of the time-varying NAIRU against the time-invariant NAIRU. Thus, it would seem reasonable to adopt the time-invariant NAIRU as the initial value for the time-varying NAIRU when implementing the Kalman filter.

The second question is how to choose the variance of the time-varying NAIRU innovation term (ν). We can express the question in the following fashion. Suppose the inflation rate changes due to a shock that is not explicitly captured by explanatory variables such as the output gap and import prices. The question is whether this change in inflation should be attributed to the regression errors (ε) or to a change in the NAIRU.

Theoretically, there is no problem in estimating the variances of ν and ε separately, but these estimations are very hard in practice. Assuming that it moves at all, the NAIRU moves only very slowly. This implies that the variance of ν is expected to be quite small. As pointed out by Stock and Watson (1998), when we estimate the variance of a state variable that moves very slowly by the maximal likelihood method, it is hard to reject the null hypothesis of "zero variance." In fact, when estimating the variances of ν and ε with a variety of sample periods, we encounter many cases where the variance of ν, which determines the behavior of the NAIRU, is found not significantly different from zero.[5]

Our approach to the above inconvenience is to choose the ratio ($=\theta$) of the variance of ν to the variance of ε so as to attain a reasonable smoothness in the movement of the NAIRU. We plot three paths of the NAIRU under differing assumptions of $\theta=1$, 1/5, and 1/10 in Chart 3. With $\theta=1$ (the broken line), we have a NAIRU whose volatility is unreasonably large. With $\theta=1/10$ (the thin line), we obtain one whose movement is too smooth for us to discriminate between the time-varying NAIRU and the time-invariant NAIRU. We therefore choose to adopt $\theta=1/5$ (the thick line) as the standard case in this paper.

The Phillips curve estimated under the assumption of a time-varying NAIRU is shown in Chart 2(2). The R^2 is 75 percent. This figure is only slightly greater than that obtained under the assumption of a time-invariant NAIRU (71 percent). However, the estimated coefficient on the output gap (β) is twice as large (0.23) as that obtained

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[5] It is reported in the literature of the US empirical studies that when a maximum likelihood estimator is used, the variance of the time-varying NAIRU is frequently estimated to be zero. The unbiased estimator introduced by Stock and Watson (1998) is a useful alternative when the maximum likelihood estimate of the variance is expected to be very close to zero. Gordon (1998) uses this method to estimate the variance of the US NAIRU. A further evaluation of its usefulness in estimating the variance of the time-varying NAIRU is desirable also for Japan.

in the time-invariant NAIRU case, and its significance level also rises. These results suggest that by assuming a time-invariant NAIRU, we may wrongly attribute a change in the inflation rate to an adjustment in inflation expectations or a movement in import prices, even when it is the business cycle that is the true source of the inflation variation. By assuming a time-varying NAIRU, we can rectify this misunderstanding and obtain a firmer grasp of the Phillips curve relationship between the inflation rate and real activity.

The estimated time-varying NAIRU is shown in Chart 4 (the thick line). The NAIRU is estimated to have been about –4 percent in the 1980s. Since the early 1990s, however, it has followed a downward trend, declining more than 3 percent between the second quarter of 1992 and the second quarter of 2002. We should be careful, however, in evaluating this estimate, since the standard error of the NAIRU is 0.7 percent (the 67 percent confidence interval is shown by the dotted lines) and the 95 percent confidence interval containing the estimate spans a full 1.4 percent. Note, however, that the time-invariant NAIRU is far from free from uncertainty, and its standard error (0.8 percent) is in fact greater than that of the time-varying NAIRU.

Next, comparing the output gap and the NAIRU, we measure inflationary and deflationary pressure since the 1990s (also shown in Chart 4). In 2000, the output gap (the thin line) fell inside the 67 percent confidence interval (the area between the dotted lines), which implies a temporary respite from recession-induced deflationary pressure. The acceleration of deflation in 2000 may be attributed to a structural break in the old-style pricing system, at the forefront of which were the apparel and food industries (see Kamada and Hirakata [2002] for a reference). Also noteworthy is upward pressure on the inflation rate in 1997, when the output gap run over the upper bound of the confidence interval.

Finally, we investigate to what extent the accuracy of inflation forecasts improves when we assume a time-varying rather than a time-invariant NAIRU. Starting from the first quarter of 1995, Chart 5 presents a one-quarter-ahead inflation rate forecast and compares it with the actual inflation rate for each quarter. The result seems to suggest the superiority of the time-varying NAIRU to the time-invariant NAIRU, although the difference is tiny. In fact, the root mean squared forecast errors (RMSE) through 1999 is 0.80 percent with the time-invariant NAIRU, while it is 0.57 percent with the time-varying NAIRU. Since 2000, however, the accuracy of inflation forecasts that employ the time-varying NAIRU has deteriorated. We return to this problem and provide a detailed discussion in Section IV.

C. Estimation of the Inflation-Neutral Potential Rate of Growth

The inflation-neutral potential rate of growth can be estimated by adding together its three constituent components (see equation (2-10)): the rate of technological progress, the growth rates of the production factors, and the shift in the NAIRU. Here we explain briefly how to estimate the first two components (see Kamada and Masuda [2001] for detail), and we also summarize the characteristics of the inflation-neutral potential rate of growth).[6]

We begin with the estimation of the growth rate of TFP. For convenience, we rearrange equation (2-5) slightly.

$$\ln A = \ln Y - \{\alpha \cdot \ln \eta + (1-\alpha) \cdot \ln \gamma\} - \{\alpha \cdot \ln L^{*} + (1-\alpha) \cdot \ln K\} \ . \qquad (3\text{-}2)$$

The left-hand side is called the *Solow residual,* from which TFP (A) may be extracted. A modification, however, is required before we are able to take the Solow residual as TFP, since the former contains measurement errors in the capacity utilization rates and changes in the quality of production factors as well as measurement errors in real GDP. We remove this noise by HP-filtering the Solow residuals. The adopted smoothing parameter is 1600, as recommended by Hodrick and Prescott (1997).

We estimate the potential input of production factors as follows. We take the existing capital stock to be self-evidently the potential capital input. The labor force is calculated by multiplying hours worked per capita and the total number of employed workers. Potential hours worked per capita are obtained by splicing together the trend lines fitted to regular working hours and the maximal amount of overtime observed in

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[6] Hirose and Kamada (2001) introduce a new technique for direct estimation of the inflation-neutral potential output without appeal to the time-varying NAIRU. For application, they estimate the Phillips curves for G7 countries.

the past. We divide employed workers into two groups: workers aged 15 to 64 and those aged 65 or over. For each group, we plot the ratio of the number of employed workers over the total population and find its ceiling, which we assume represents the maximal level of employment. Finally, we create a specific weighted average of the potential growth rates of the capital and labor inputs in order to obtain the potential growth rate for production factors as a whole.

Now we have the three components necessary for the estimation of the inflation-neutral potential rate of growth. Chart 6 sums up these components and shows how much each component has contributed to the development of potential output since 1985. In the chart, the thick line represents the inflation-neutral potential rate of growth and the bars show the contributions of each of the three components. In the 1980s, the inflation-neutral potential growth rate is estimated to have been over 4 percent per annum. This rapid growth was fed by aggressive capital accumulation, increasing labor force, and the rapid progress of productivity.[7] Thereafter, the inflation-neutral potential rate of growth declined rapidly in the early 1990s and has stayed around 1 percent since 2000. It is noteworthy that all three components have followed downward trends recently. This suggests that the slowdown of potential growth originates from a variety of sources.

We conclude this section with a description of some of the characteristics of the inflation-neutral potential rate of growth since the 1990s, offering also a brief commentary on possible driving forces behind them. We note first of all the slowdown in potential growth that occurred during the period 1990-93. This may be attributed to a "reduction in hours worked per capita," the declining pace of capital accumulation triggered by the bursting of the asset-price bubble, and the weak progress of TFP. Around 1996, although TFP continued to fall gradually, there was a brief period of capital accumulation that coincided with a short period of economic recovery. These opposing effects cancelled each other out so that we observe a potential rate of growth almost unchanged. From 2001 onward, the growth of capital accumulation and

[7] The rise in the labor participation rate accelerated during the expansion of the asset bubble. The maximum hours worked increased partly because of the rise in women's labor participation promoted by the *Equal Employment Opportunity Law between Men and Women* (1985).

technological progress is seen to have slowed. However, since this has coincided with a cessation of the NAIRU decline, the potential growth rate has been saved from a substantial decline.

IV. DISCUSSION

So far we have learned why the estimation of the movement of the NAIRU is relevant for the estimation of the potential rate of growth and how the Japanese NAIRU has developed since the latter half of the 1980s. Here we pick up and discuss some issues that are important in making practical use of estimates of the potential growth rate and the NAIRU. We focus on the following three issues: (i) the uncertainty in the NAIRU estimate caused by data accumulation; (ii) the instability of the Phillips curve parameter estimates; and (iii) the difficulties that attend the specification of supply-side factors.[8]

A. Effects of Data Accumulation on the NAIRU Estimate

Every time new data arrive, the estimate of the NAIRU should be revised. In order to examine the effects of such revision, we carry out the following experiment. First, we use a given sub-sample of our data to estimate the NAIRU series and retain the last element of this series. Next, we expand the sub-sample by one quarter (the beginning of the sample is fixed) and repeat the same process. We call the time series thus obtained the *real-time time-varying NAIRU*. The NAIRU estimate obtained from the full sample is called the *final time-varying NAIRU*.[9] The thin line in Chart 7 is the real-time time-varying NAIRU, while the dotted lines trace out the associated one-

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[8] Staiger, et al. (1997) emphasize the extent of the uncertainty in the NAIRU estimate and cast doubts on its usefulness from a policymaking perspective.

[9] The Kalman filter sequentially estimates the values of a state variable by expanding the sample gradually. This is technically known as filtering. Once the most recent value of the state variable is obtained, we can re-estimate all the past values of the state variable retrospectively. This is technically known as smoothing. The real-time time-varying NAIRU consists of the state-variable estimates obtained by filtering, while the final time-varying NAIRU is made up of those obtained by smoothing.

standard error confidence interval. The thick line is the final time-varying NAIRU. The differences between them show us to what extent the NAIRU estimate is revised over time. Trivially, there is no revision at the end of the full sample.[10]

Two points are worth remarking. First, apart from towards the end of the sample (the last one or two years), there is no tendency for a larger sample size to cause the differences between the real-time time-varying NAIRU and the final time-varying NAIRU to shrink. Put differently, assuming that it is possible to forecast the NAIRU at all, we can provide predictions at most one to two years ahead. Second, in spite of this, the final time-varying NAIRU falls mostly within the one-standard-error (67 percent) confidence interval. That is, our forecast is wrong with a probability of only one third. This implies that the real-time time-varying NAIRU provides us with enough information for our immediate purposes.

It cannot, however, be ignored that the arrival of new data necessitates not only the revision of the current estimate but also the retrospective revision of past estimates as well. In Chart 8, where we start with the data up to the second quarter of 2000 and expand the sample year by year, we show to what extent the NAIRU is revised retrospectively. The results show that only one-year (four-quarter) sample addition has substantial retrospective effects.[11]

B. Stability of Estimates of Phillips Curve Parameters

Here we check the stability of the estimates of the Phillips curve parameters. We are particularly interested in the β in equation (2-11). Chart 9 plots the β estimates both for the time-invariant NAIRU and the time-varying NAIRU, where the latter is obtained by carrying out a quarter-by-quarter expansion (from the first quarter of 1995 onwards) of a sample with a fixed starting period (the second quarter of 1983).

[10] Of course, the NAIRU value for the current end of the sample will be revised with the arrival of new quarterly data, and at that point the real-time time-varying NAIRU for this period will potentially depart from the final time-varying NAIRU.

[11] The estimate of the output gap is also subject to revision due to data accumulation and revision. See Orphanides and van Norden (1997) for the US and Kamada and Masuda (2001) for Japan.

Assuming a time-invariant NAIRU, β is estimated to have fallen from 0.45 to a level slightly higher than 0.1, leading to the conclusion that the Phillips curve relationship between real activity and inflation has broken down over the course of this decade. On the other hand, when we assume a time-varying NAIRU, β is estimated to have been stable at least until 2000. Nevertheless, even under the time-varying NAIRU assumption, the β estimate is quite unstable from 2000 onward, suggesting the occurrence of some structural changes.

We have several hypotheses to explain why the estimate of β has become unstable since 2000. The first is that the time-series properties of the CPI underwent a change when the benchmark year for the index was shifted from 1995 to 2000. In fact, when the Phillips curve is estimated with a dummy variable that takes 1 from the first quarter of 2000 and 0 before it, the stability of the β estimate improves substantially (Chart 10(1)). It is often pointed out that CPI deflation has recently accelerated because of the addition to the index of new items, such as personal computers and overseas travel. In fact, when we exclude these items from the CPI and estimate the Phillips curve (Chart 10(1) again), the stability of the β estimate improves to some extent.

The second hypothesis for the instability of the β estimate is as follows. The true NAIRU has been shifting downward at a higher speed than before, whereas we take this speed to be constant in estimating the NAIRU. Consequently, the deviation of actual output from the NAIRU is overestimated.[12] When we test this hypothesis, the question arises whether the variance of the Phillips curve errors has increased along with the acceleration in the shifting of the NAIRU. We treat this question in two steps.

Case 1: The variance of the Phillips curve errors remains untouched, while only the shifting of the NAIRU has accelerated.

Case 2: The variance of the Phillips curve errors has increased along with the acceleration of the shifting of the NAIRU.

We begin with Case 1 and specify the variance structure of the NAIRU as follows.

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[12] We cannot deny the possibility that the time-series properties of the output gap have changed. We cannot, however, distinguish this hypothesis from the hypothesis of a change in the speed of the shifting of the NAIRU. For this reason, we focus on the latter hypothesis.

$$\sigma_\nu^2 = \begin{cases} \sigma_\varepsilon^2/5 & \textit{until} \;\; 2000Q3. \\ (\sigma_\varepsilon + \sigma_+)^2/5 & \textit{since} \;\; 2000Q4. \end{cases}$$

We test the null hypothesis "σ_+ is zero" and find that it cannot be rejected. In this case, we are led to the conclusion that the speed at which the NAIRU is shifting remains the same and thus offers no insight into the reasons behind the recent instability of the β estimate.

We proceed to examine the plausibility of Case 2. We specify this case as follows.

$$\sigma_\varepsilon^2 = \begin{cases} \sigma_{\varepsilon 1}^2 & \textit{until} \;\; 2000Q3. \\ \sigma_{\varepsilon 2}^2 & \textit{since} \;\; 2000Q4. \end{cases}$$

$$\sigma_\nu^2 = \begin{cases} \sigma_{\varepsilon 1}^2/5 & \textit{until} \;\; 2000Q3. \\ \sigma_{\varepsilon 2}^2/5 & \textit{since} \;\; 2000Q4. \end{cases}$$

We find that the estimate of $\sigma_{\varepsilon 2}$ is twice as large as $\sigma_{\varepsilon 1}$, implying a doubling of the speed at which the NAIRU has been shifting.[13] Moreover, as shown in Chart 10(2), the estimate of β becomes more stable than was observed under the assumption of a constant variance structure.

There are two reasons for the recent acceleration in the shifting of the NAIRU. First, as witnessed in the downward trend of the labor participation rate, the Japanese economy has become prone to unemployment partly because of the weaker attitude toward work displayed by the younger generation. Second, it may be that an intensified mismatch in the labor market has strengthened the downward pressure on the NAIRU. The latter is supported by two facts taken together: the increase in employment has been slow in comparison to the increase in job offers; and the expansion of the output gap has not been accompanied by an acceleration in the rate of deflation.[14]

We have presented the two possible sources for the recent instability of the Phillips curve parameters: (i) changes in the time-series properties of the CPI and (ii) an acceleration in the shifting of the NAIRU. We consider the second possibility to be

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[13] The estimates of variances are $\sigma_{\varepsilon 1}$=0.59 and $\sigma_{\varepsilon 2}$=1.03.

[14] See Osawa et al. (2002) and Nakada (2002) for a treatment of possible causes of the recent decline in the labor participation rate and for further detail on the mismatch in the labor market.

more plausible for two reasons: the estimates of the Phillips curve parameters are more stable and the decline of the estimates since 2000 is smaller.[15]

C. Specification of Supply-Side Factors

There are a variety of factors other than the shifting of the NAIRU that make the Phillips curve unstable. Movements in import prices provide a typical example. Fluctuations in oil prices and changes in exchange rates both impact strongly on domestic prices, although the extent and speed of their impacts vary. Put differently, if changes in import prices are a crucial determinant of domestic inflation, then by ignoring this factor in Phillips curve estimation, we will create bias in our estimates of the NAIRU as well as of the Phillips curve parameters.

In order to counteract this bias, we include import prices as an explanatory variable in the Phillips curve in this paper. The estimation result suggests that import prices are indeed significant (Chart 2). The fit is not greatly improved by including import prices, however, and thus the NAIRU estimate is almost untouched (Chart 11). We cannot deny the possibility that this result is reached because of our possibly wrong data transformation. Therefore, it is desirable that more research is devoted to the question of how we can incorporate supply-side factors like import prices into the Phillips curve.

V. CONCLUSION

In this paper, the inflation-neutral potential output is defined as the level of output at which the inflation rate would be neither accelerating nor decelerating. The potential rate of growth may be decomposed into three parts: (i) the rate of technological progress, (ii) the growth rates of the production factors, and (iii) the shift in the NAIRU. We provide a detailed discussion of the plausibility of shifts in the NAIRU as well as

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[15] However, as mentioned in Section IV A, since there are various kinds of uncertainty contained in the time-varying NAIRU, the instability of the β estimate may disappear, as data accumulates in future. Thus, more time is required, before it is appropriate to come to any firm conclusion regarding this stability problem.

presenting an empirical technique to test for such shifts.

According to the results of our empirical analysis, the above three factors all contributed to the lowering of the inflation-neutral potential rate of growth to about 1 percent in Japan in the early 1990s. In particular, the shifts in the NAIRU continued to lower the potential rate of growth around the mid-1990s.

The estimates of the Phillips curve parameters have been unstable since 2000, because there has recently been an acceleration in the shifting of the NAIRU. Furthermore, being subject to revisions in line with the accumulation of new data, the NAIRU estimate is very uncertain. For this reason, considerable caution is advisable when evaluating the resulting estimate.

Movements in oil prices and exchange rates affect the CPI. To the extent that these effects are important, there occurs a bias in our estimates of both the Phillips curve parameters and the NAIRU itself, when they are excluded from the list of explanatory variables in the Phillips curve. In this paper, we include import prices as a typical supply-side factor. The fit of the Phillips curve, however, does not improve and the estimate of the NAIRU is almost untouched.

APPENDIX A

OKUN'S LAW AND THE PHILLIPS CURVE

While this paper makes use of the output gap as an indicator of the balance between aggregate supply and demand, it is the unemployment rate that is used in a traditional Phillips curve estimation. This is based on the assumption that the unemployment rate reflects the balance between aggregate supply and demand in the economy. We can restate this assumption using the following equation.

$$\ln\gamma = \psi + \phi \cdot \ln\eta \, . \qquad \text{(A-1)}$$

Denote the unemployment rate by U. We then have $\ln\eta = -U$. The output gap is given by

$$G = (1-\alpha)\cdot\psi - (\phi - \alpha\cdot\phi + \alpha)\cdot U \, . \qquad \text{(A-2)}$$

This is simply a restatement of *Okun's Law*.

If the same relationship holds for inflation-neutral capacity utilization rates, we can rewrite the output-gap-based NAIRU as follows.

$$G^N = (1-\alpha)\cdot\psi - (\phi - \alpha\cdot\phi + \alpha)\cdot U^N \, ,$$

where U^N is the unemployment-rate-based NAIRU. Substituting these equations into equation (2-11), we obtain the NAIRU-type Phillips curve developed by Gordon (1997).

$$\pi_t = \pi_t^e + \beta'\cdot(U_t - U_t^N) + \varepsilon_t \, , \quad \beta' = -(\phi - \alpha\cdot\phi + \alpha)\cdot\beta \, . \qquad \text{(A-3)}$$

The Samuelson-Solow (1960) type of Phillips curve is obtained when we assume that the NAIRU is time-invariant.

The above argument contains two assumptions: (i) there is a positive correlation between the capacity utilization of capital and that of labor; (ii) the same positive relationship observed in the actual capacity utilization rates of the production factors holds in the relationship between the inflation-neutral capacity utilization rates. The first assumption is justified by demonstrating the existence of a relationship between the actual capacity utilization rates of capital and labor (Chart A1). In fact, when we estimate equation (A-1), we obtain parameter estimates of $\phi = 2$ and $\psi = 0$. That is,

$$\ln \gamma_t = 2 \cdot \ln \eta_t + \xi_t . \qquad \text{(A-4)}$$

In this case, the 67 percent confidence interval containing the regression curve has a span of 3 percent.

The second assumption is, however, rather harder to justify. This is because inflation-neutral capacity utilization rates do not vary with the business cycle. When the production technology becomes obsolete rapidly and when products are only short-lived, entrepreneurs may be discouraged from maintaining a large production capacity. Consequently, this may raise the inflation-neutral capacity utilization rate of capital. On the other hand, a decline in the inflation-neutral capacity utilization of labor is equivalent to a rise in the natural rate of unemployment. The latter is raised by the expansion of unemployment benefits and by the spread of higher education, while it is lowered by increasing female participation in the labor market.

These arguments suggest that the two inflation-neutral capacity utilization rates are driven by their own specific shocks, and thus there is no reason for the two rates to be positively correlated. Moreover, there is no rationale for the claim that the inflation-neutral rates should display the same relationship as the actual capacity utilization rates. Therefore, use of the unemployment rate as a proxy for the output gap is not an approach that is considered desirable in this context.

APPENDIX B

INFLATION-NEUTRAL CAPACITY UTILIZATION RATES OF THE PRODUCTION FACTORS

In this appendix, we investigate possible combinations of the inflation-neutral capacity utilization rates of capital and labor. In theory, we can decompose the NAIRU (G^N) into the inflation-neutral capacity utilization rate of capital (η^N) and that of labor (γ^N). The information in the NAIRU is not, however, sufficient to identify these utilization rates separately. More concretely, for each value of G^N, the combinations of η^N and γ^N that satisfy the following equation all qualify as possible inflation-neutral capacity utilization rates.

$$\ln\gamma^N = -\tfrac{\alpha}{1-\alpha}\ln\eta^N + \tfrac{1}{1-\alpha}G^N . \qquad \text{(B-1)}$$

In Chart B1, we plot all possible combinations in the $(\ln\eta^N, \ln\gamma^N)$ plane. Our empirical analysis tells us that the 67 percent confidence interval of G^N lies between –6.5 percent and –0.83 percent, and thus that the two inflation-neutral capacity utilization rates fall in between the two downward-sloping lines.

An additional assumption is required to restrict the area in which the inflation-neutral capacity utilization rates may lie. Our assumption is that when the output gap gets close to the NAIRU, the actual capacity utilization rates of capital and labor approach their own inflation-neutral levels. The corollary of this assumption is that the following relationship holds when the output gap coincides with the NAIRU.

$$\ln\gamma_t^N = 2\cdot\ln\eta_t^N + \xi_t . \qquad \text{(B-2)}$$

(Note that this assumption is weaker than the assumption made in Appendix A, which claims that equation (B-2) holds anytime and anywhere.) The inflation-neutral capacity utilization rates are located in between the two upward-sloping lines. Combining the two arguments above, we expect the inflation-neutral capacity utilization rates to be located somewhere in the crossing confidence intervals of (B-1) and (B-2).

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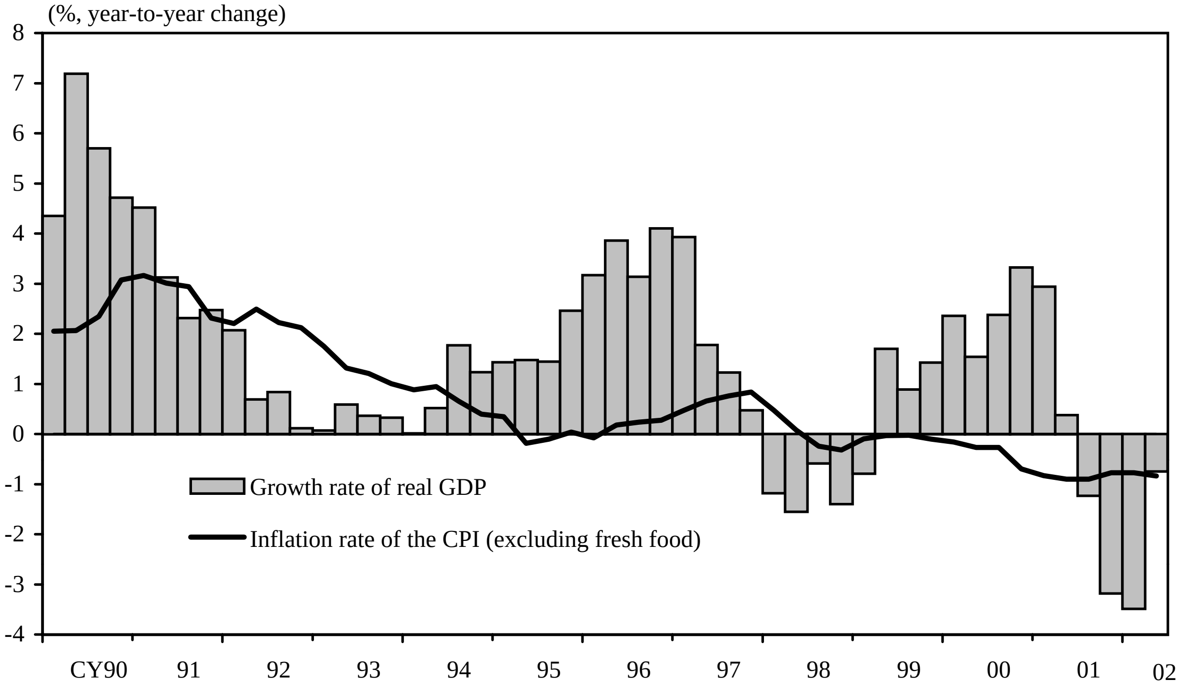
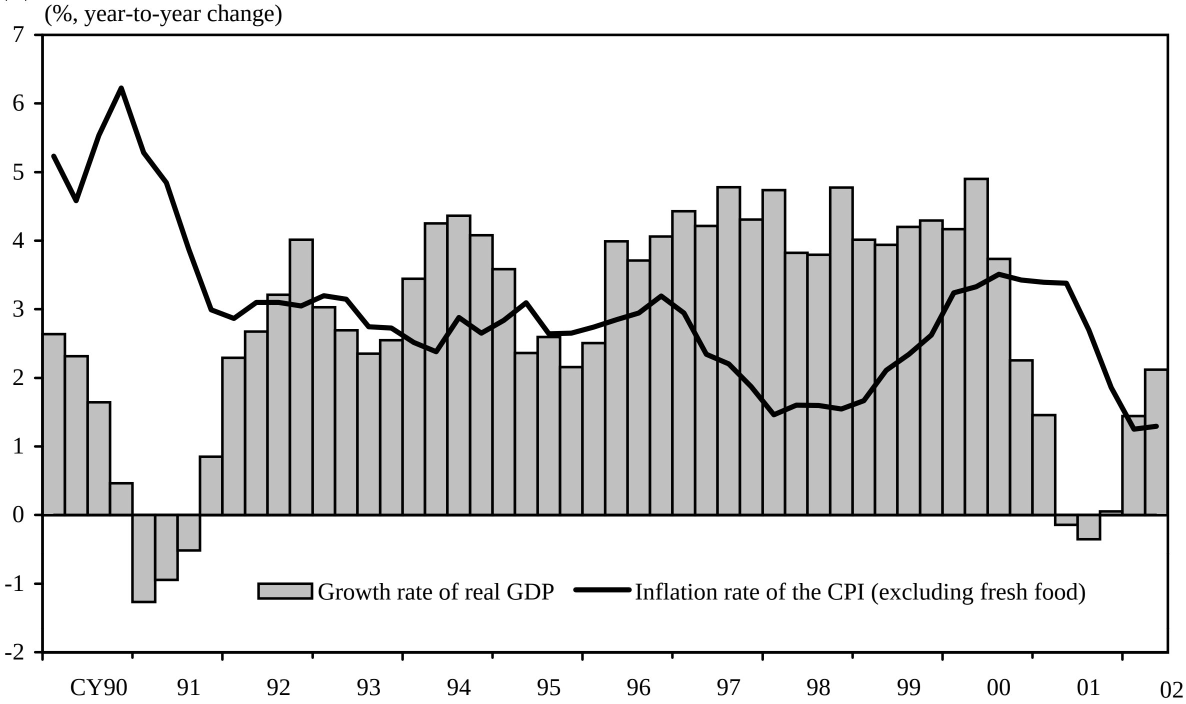
(Chart 1)

Output Growth and Inflation in Japan and the US

(1) Japan



(2) US



Notes: 1.Japanese CPI is adjusted for consumption tax.
2. Japanese GDP is composed of preliminary figures for 2001/Q2 onward, "reference series" for 1994/Q1-2001/Q1, and revised figures prior to 1993/Q4.

Sources: Japanese data are based on the *National Accounts* released by the Cabinet Office and the *Consumer Price Index* released by the Ministry of Public Management, Home Affair, Posts and Telecommunication; US data are based on *International Financial Statistics* released by the International Monetary Fund.

Estimated Phillips Curves

(1) Time-Invariant NAIRU

$$\pi_t = 0.84 \cdot \Sigma_{i=1}^{4} \pi_{t-i} / 4 + (1 - 0.84) \cdot \Sigma_{i=5}^{8} \pi_{t-i} / 4 + 0.11 \cdot (G_t - G^N) + 0.02 \cdot ipi_t + \varepsilon_t$$

(6.58) (2.46) (3.31)

$$G^N = -4.74$$

(6.58)

(Sample: 1983/Q2-2002/Q2, quasi-R^2=0.71, t-value in parentheses.)

[Variables]

π :CPI inflation rate (excluding fresh food, adjusted for consumption tax)

G :Output gap (adjusted by the capacity utilization rate in the non-manufacturing sector)

G^N : NAIRU

ipi : Import prices (deviation of the current rate of change from the moving average for past four quarters)

(2) Time-Varying NAIRU

$$\pi_t = 0.64 \cdot \Sigma_{i=1}^{4} \pi_{t-i} / 4 + (1 - 0.64) \cdot \Sigma_{i=5}^{8} \pi_{t-i} / 4 + 0.23 \cdot (G_t - G_t^N) + 0.02 \cdot ipi_t + \varepsilon_t$$

(3.88) (3.69) (2.77)

$$G_t^N = G_{t-1}^N + v_t$$

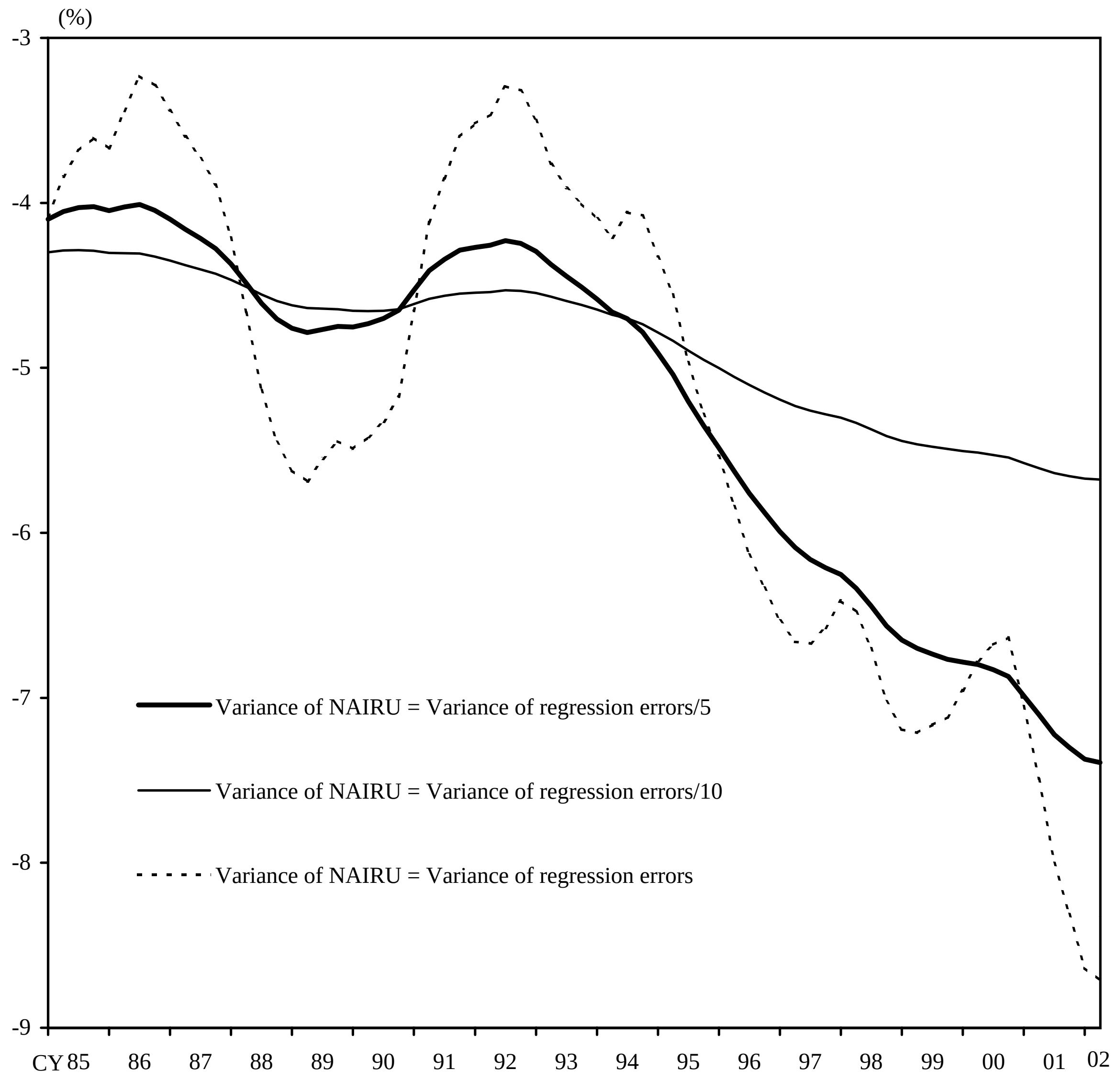
$$\sigma_\varepsilon = 0.66 \qquad \sigma_v^2 = \sigma_\varepsilon^2 / 5$$

(11.25)

(Sample: 1983/Q2-2002/Q2, quasi-R^2=0.75, z-value in parentheses.)

(Chart 3)

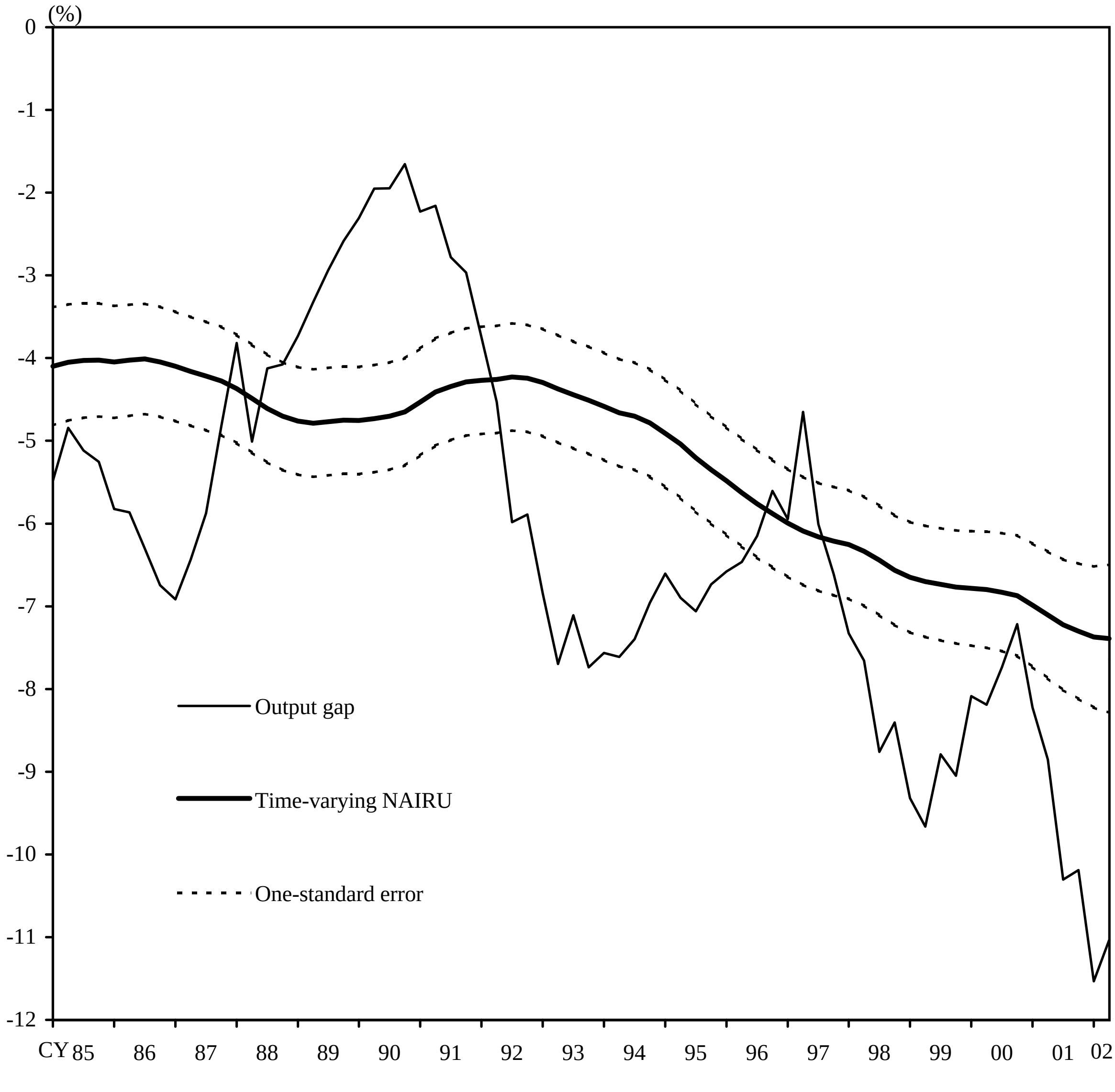
Smoothness in the NAIRU Shift



Sources: Cabinet Office, *National Accounts* , *Capital Stock of Private Enterprises Statistics* ;
Ministry of Economy, Trade and Industry, *Indices of Industrial Production* ;
Ministry of Health, Labour and Welfare, *Monthly Labour Survey* ;
Ministry of Public Management, Home Affairs, Posts and Telecommunications, *Consumer Price Index* , etc.

(Chart 4)

The Time-Varying NAIRU and the Output Gap

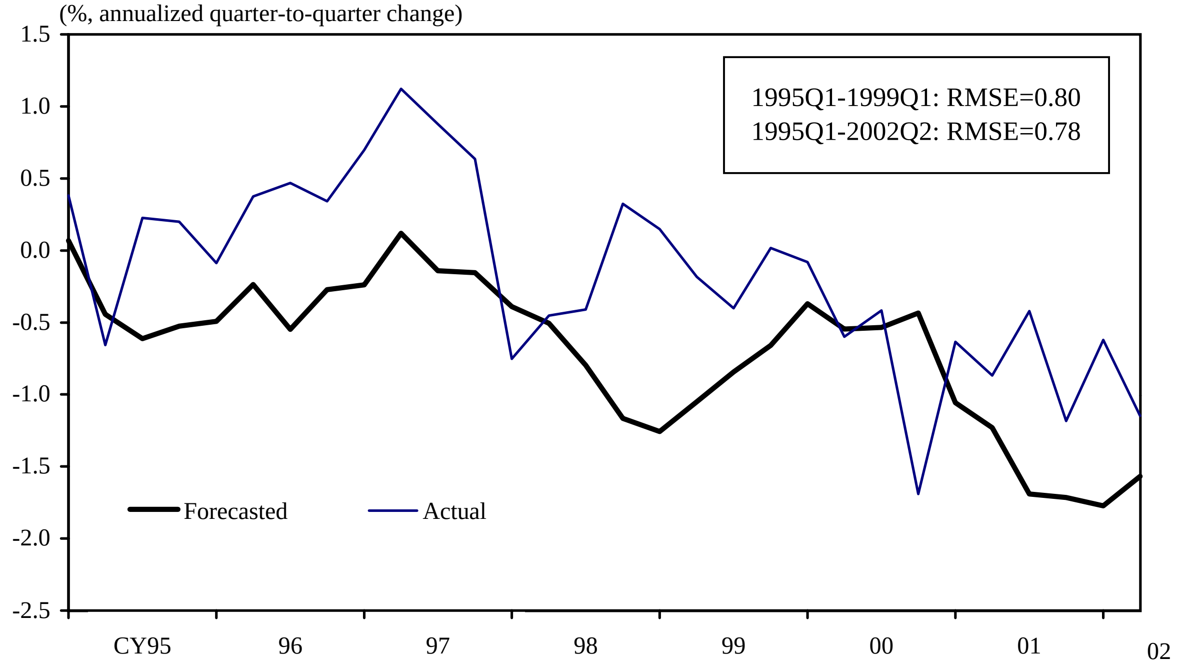


Sources: Cabinet Office, *National Accounts* , *Capital Stock of Private Enterprises Statistics* ;
Ministry of Economy, Trade and Industry, *Indices of Industrial Production* ;
Ministry of Health, Labour and Welfare, *Monthly Labour Survey* ;
Ministry of Public Management, Home Affairs, Posts and Telecommunications, *Consumer Price Index* , etc.

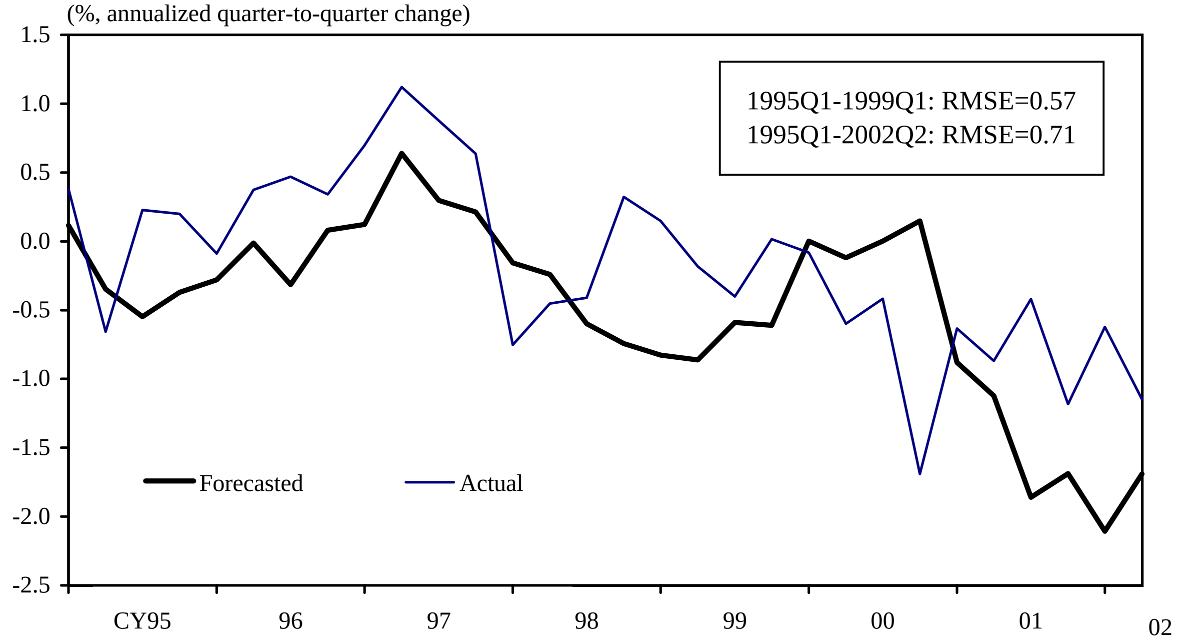
(Chart 5)

Accuracy of Inflation Forecasts

(1) Time-Invariant NAIRU



(2) Time-Varying NAIRU

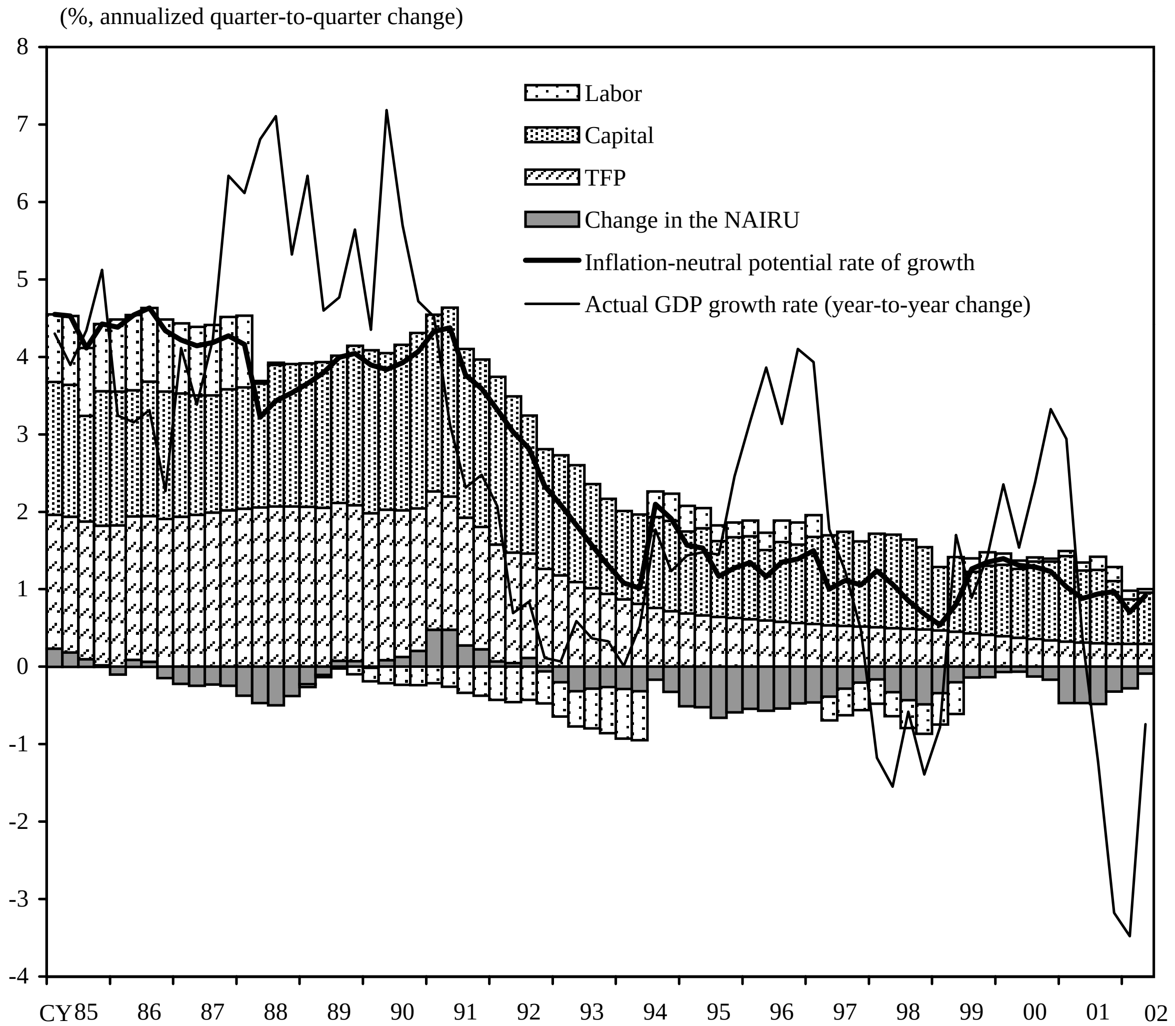


Note: In the forecasts, the time-varying NAIRU in the next period is assumed to take its value in the current quarter.

Sources: Cabinet Office, *National Accounts*, *Capital Stock of Private Enterprises Statistics*;
Ministry of Economy, Trade and Industry, *Indices of Industrial Production*;
Ministry of Health, Labour and Welfare, *Monthly Labour Survey*;
Ministry of Public Management, Home Affairs, Posts and Telecommunications, *Consumer Price Index*, etc.

(Chart 6)

Decomposition of Inflation-Neutral Potential Rate of Growth

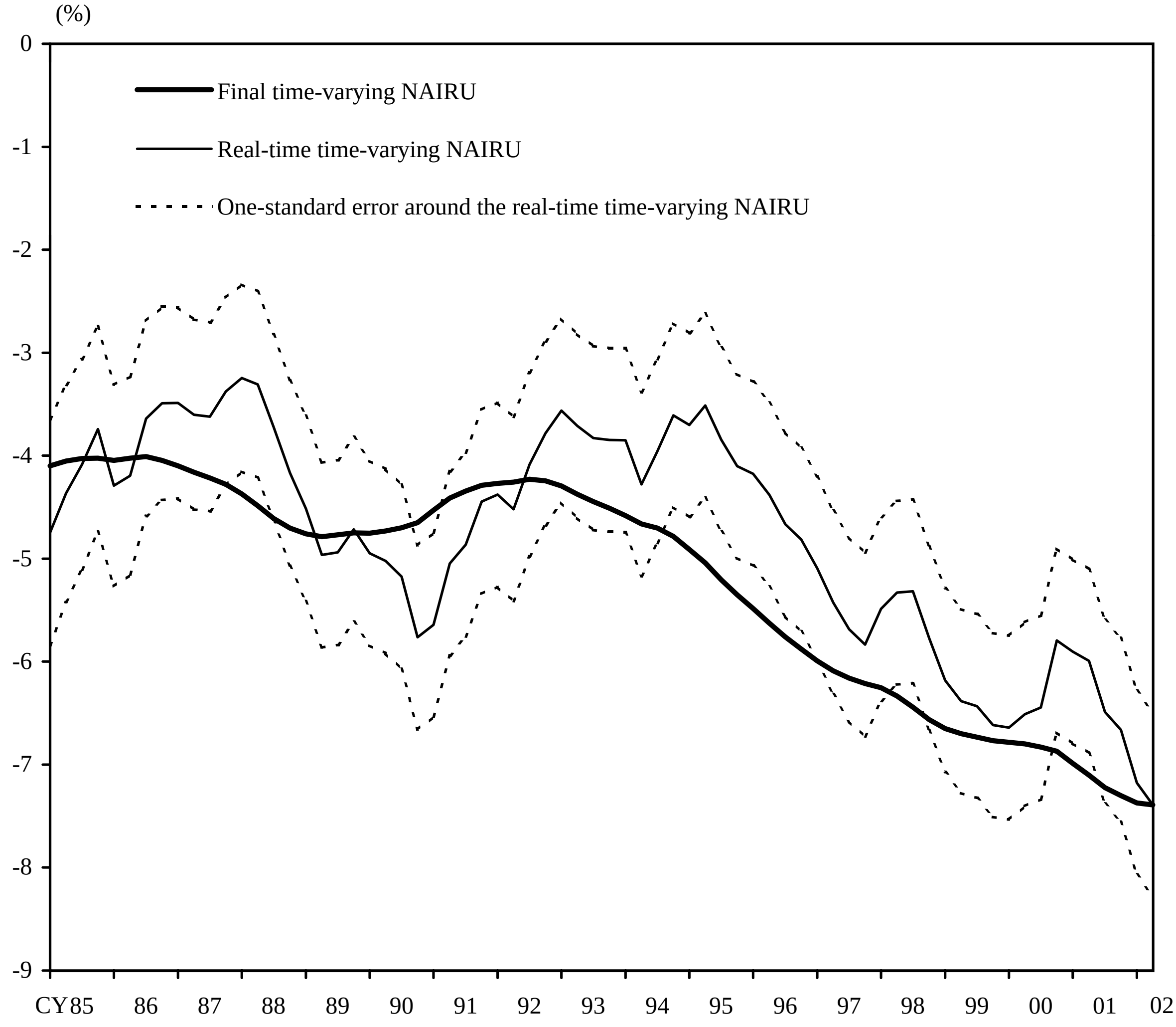


Note: Japanese GDP is composed of preliminary figures for 2001/Q2 onward, "reference series" for 1994/Q1-2001/Q1, and revised figures prior to 1993/Q4.

Sources: Cabinet Office, *National Accounts* , *Capital Stock of Private Enterprises Statistics* ;
Ministry of Economy, Trade and Industry, *Indices of Industrial Production* ;
Ministry of Health, Labour and Welfare, *Monthly Labour Survey* ;
Ministry of Public Management, Home Affairs, Posts and Telecommunications, *Consumer Price Index* , etc.

(Chart 7)

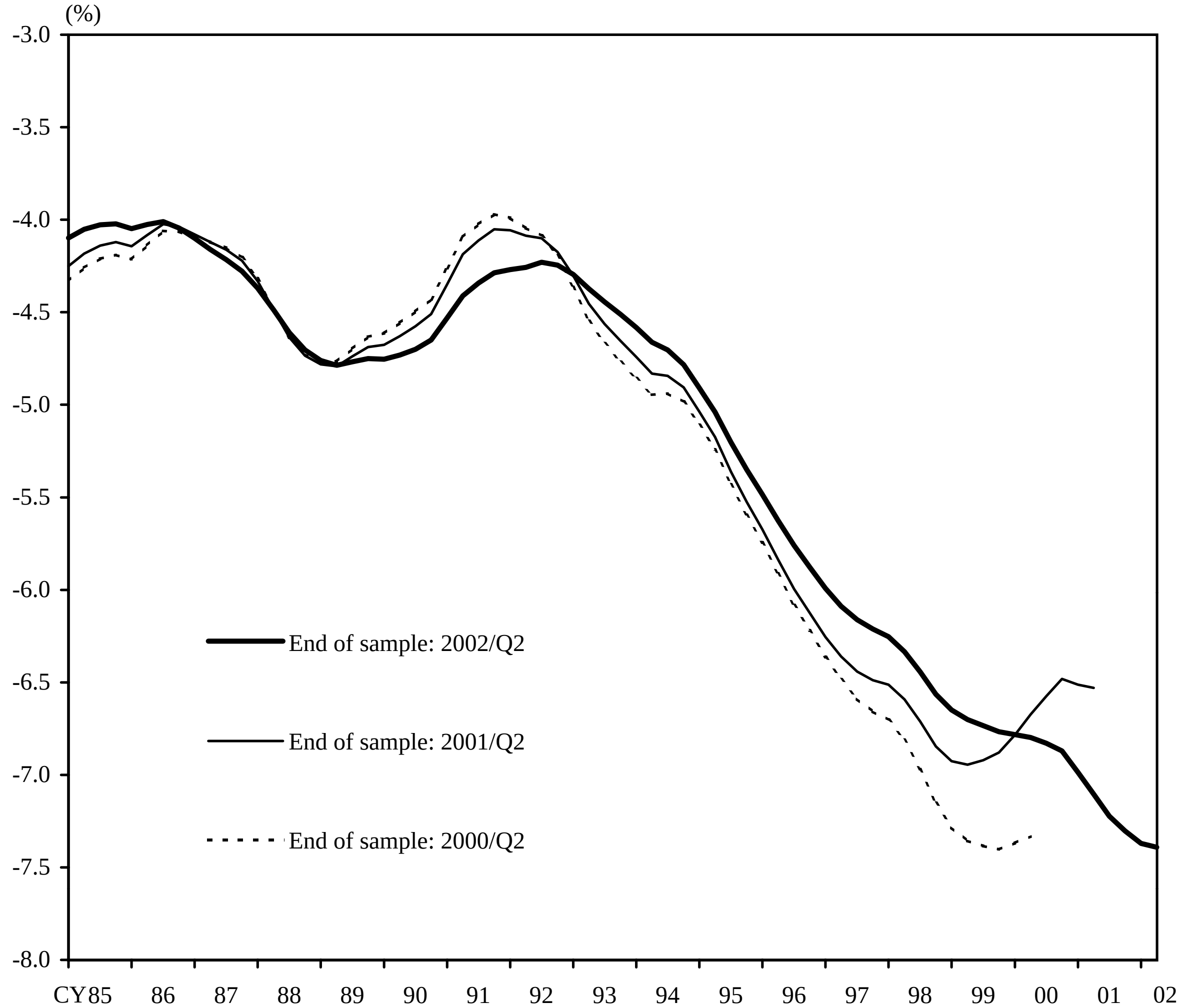
Effects of Data Accumulation on the NAIRU Estimate (I)



Sources: Cabinet Office, *National Accounts*, *Capital Stock of Private Enterprises Statistics*;
Ministry of Economy, Trade and Industry, *Indices of Industrial Production*;
Ministry of Health, Labour and Welfare, *Monthly Labour Survey*;
Ministry of Public Management, Home Affairs, Posts and Telecommunications, *Consumer Price Index*, etc.

(Chart 8)

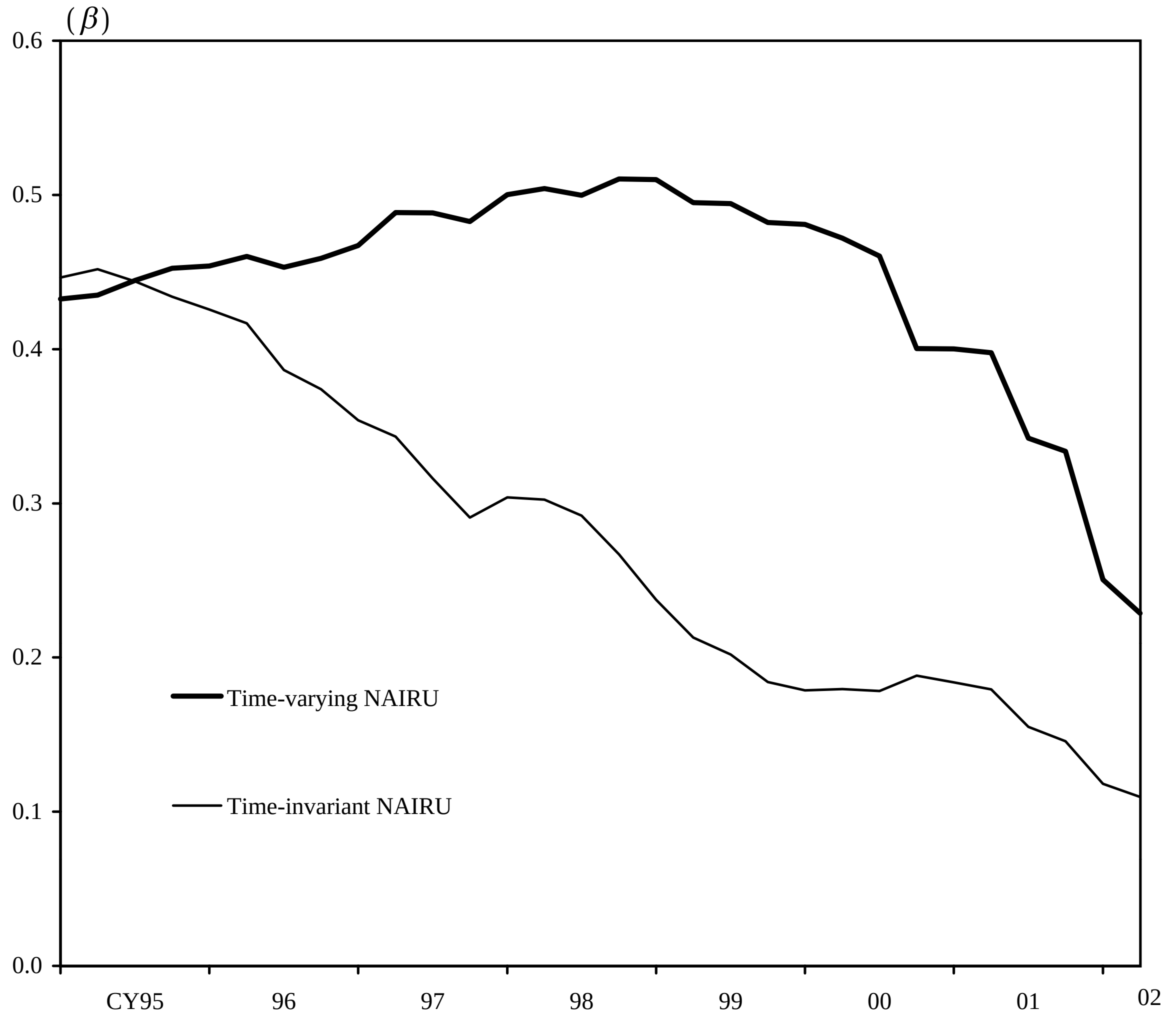
Effects of Data Accumulation on the NAIRU Estimate (II)



Sources: Cabinet Office, *National Accounts* , *Capital Stock of Private Enterprises Statistics* ;
Ministry of Economy, Trade and Industry, *Indices of Industrial Production* ;
Ministry of Health, Labour and Welfare, *Monthly Labour Survey* ;
Ministry of Public Management, Home Affairs, Posts and Telecommunications, *Consumer Price Index* , etc.

(Chart 9)

Stability of Phillips Curve Estimates (I)

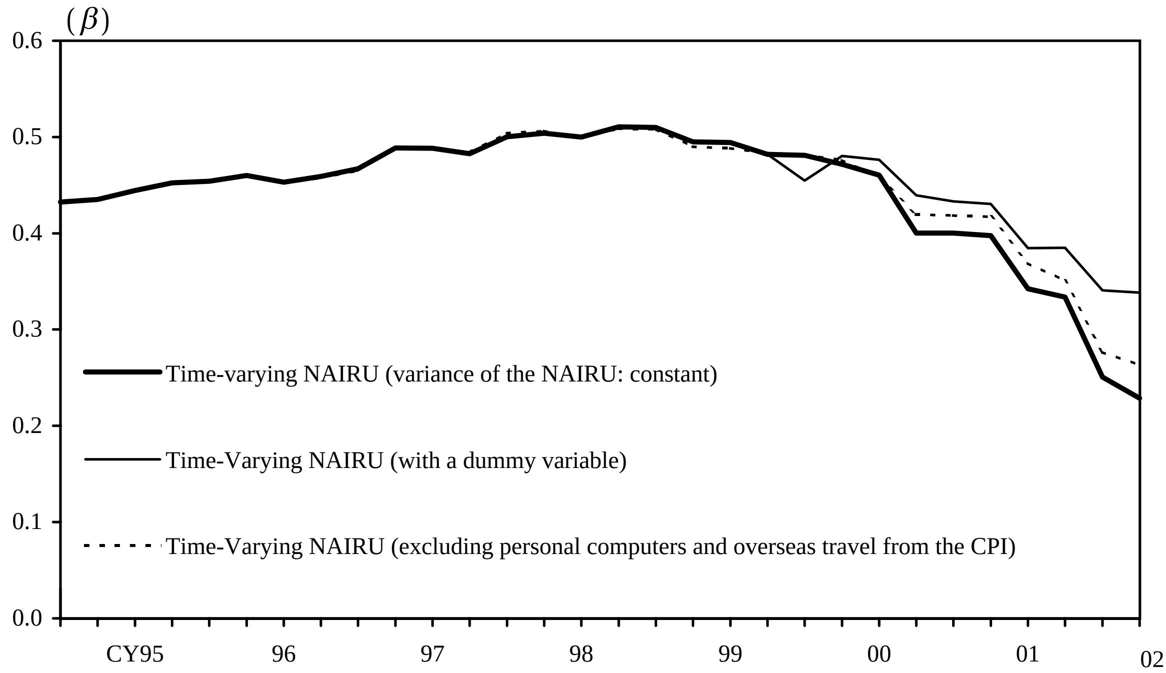


Sources: Cabinet Office, *National Accounts* , *Capital Stock of Private Enterprises Statistics* ;
Ministry of Economy, Trade and Industry, *Indices of Industrial Production* ;
Ministry of Health, Labour and Welfare, *Monthly Labour Survey* ;
Ministry of Public Management, Home Affairs, Posts and Telecommunications, *Consumer Price Index* , etc.

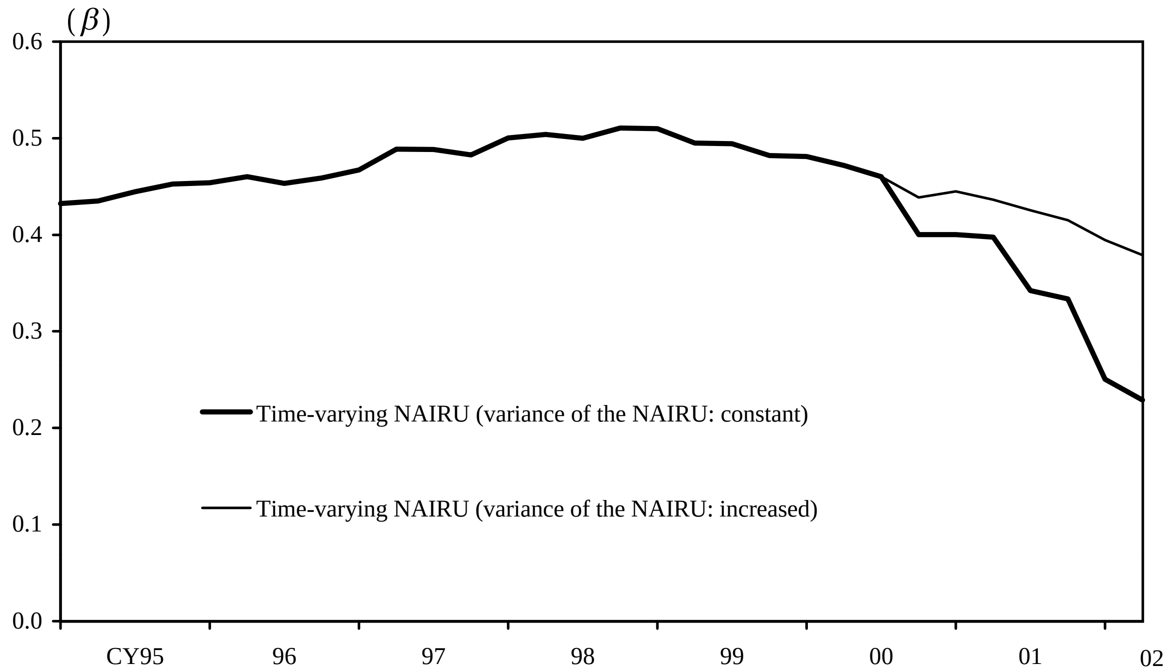
(Chart 10)

Stability of Phillips Curve Estimates (II)

(1) Possible Changes in Time-Series Properties of CPI



(2) Possible Acceleration of NAIRU Shift

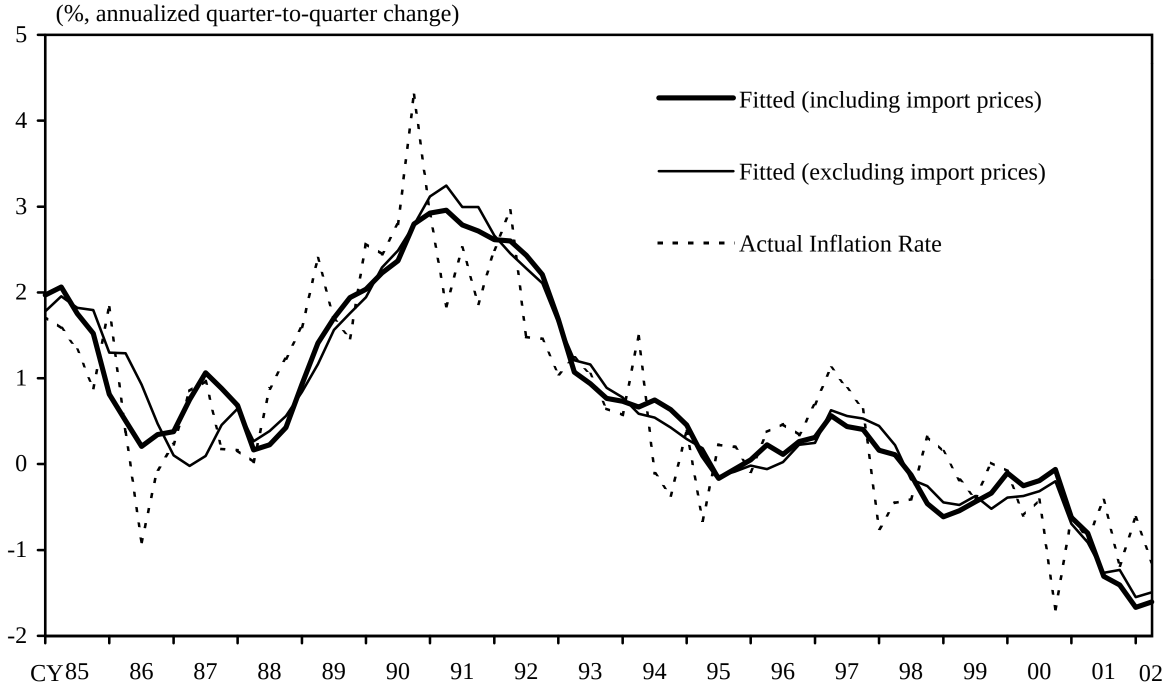


Sources: Cabinet Office, *National Accounts* , *Capital Stock of Private Enterprises Statistics* ;
Ministry of Economy, Trade and Industry, *Indices of Industrial Production* ;
Ministry of Health, Labour and Welfare, *Monthly Labour Survey* ;
Ministry of Public Management, Home Affairs, Posts and Telecommunications, *Consumer Price Index* , etc.

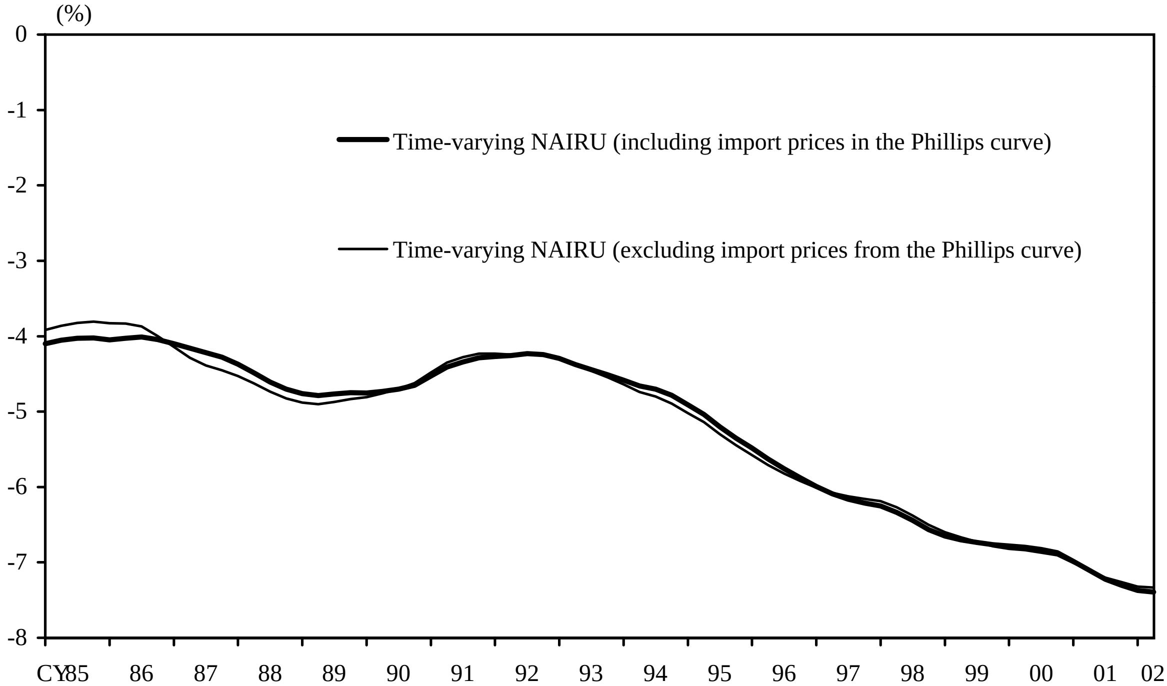
(Chart 11)

Effects of Import Prices on the Phillips Curve

(1) Fit of the Phillips Curve



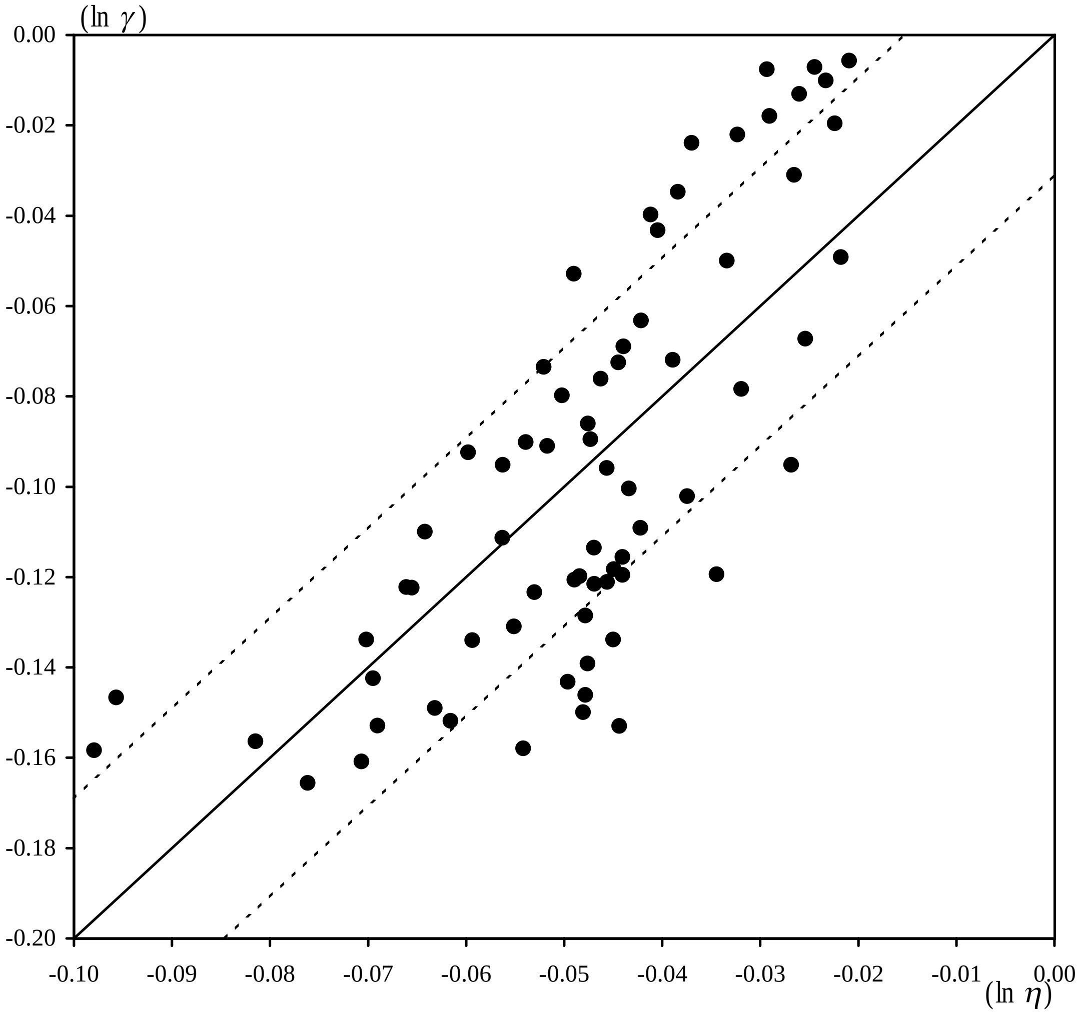
(2) Time-Varying NAIRU



Sources: Cabinet Office, *National Accounts*, *Capital Stock of Private Enterprises Statistics*;
Ministry of Economy, Trade and Industry, *Indices of Industrial Production*;
Ministry of Health, Labour and Welfare, *Monthly Labour Survey*;
Ministry of Public Management, Home Affairs, Posts and Telecommunications, *Consumer Price Index*, etc.

(Chart A1)

Capacity Utilization Rates of Capital and Labor



[Estimation Results]

$$\ln \gamma_t = -0.003 + 2.00 \cdot \ln \eta_t + \xi_t$$

(−0.27) (9.06)

(Sample: 1983/Q2-2002/Q2, R^2=0.52, standard error=0.03, t-value in parentheses.)

[Variables]

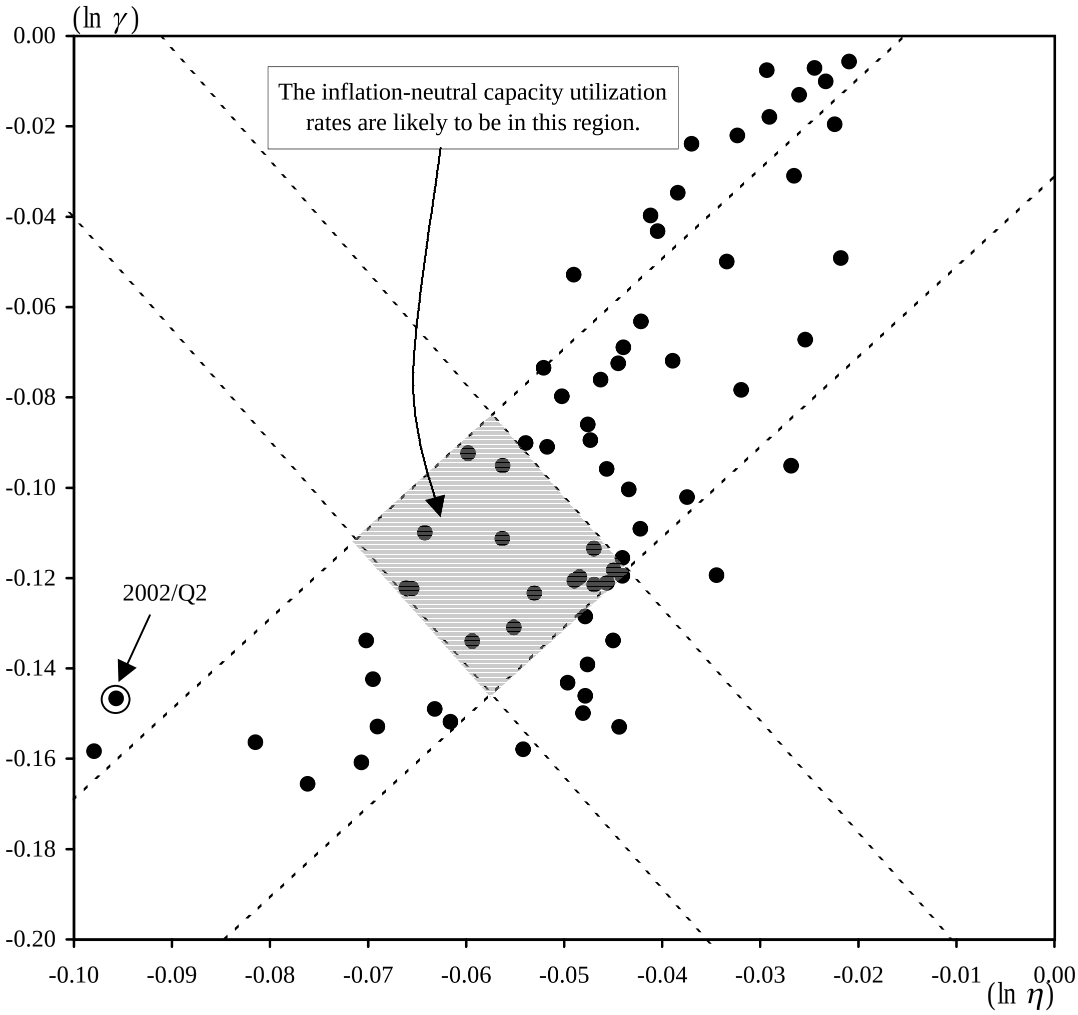
γ : Capacity utilization rate of capital

η : Capacity utilization rate of labor

Sources: Cabinet Office, *National Accounts* , *Capital Stock of Private Enterprises Statistics* ;
Ministry of Economy, Trade and Industry, *Indices of Industrial Production* ;
Ministry of Health, Labour and Welfare, *Monthly Labour Survey* ,etc.

(Chart B1)

Inflation-Neutral Capacity Utilization Rates



Sources: Cabinet Office, *National Accounts* , *Capital Stock of Private Enterprises Statistics* ;
Ministry of Economy, Trade and Industry, *Indices of Industrial Production* ;
Ministry of Health, Labour and Welfare, *Monthly Labour Survey* ;
Ministry of Public Management, Home Affairs, Posts and Telecommunications, *Consumer Price Index* , etc.