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Inflation Expectations Curve in Japan

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Abstract

In this paper, we estimate "inflation expectations curve" – a term structure of inflation expectations – combining forecast data of various agents. We use a state-space model which considers consistency among expectations at different horizons, and for relationships between inflation rate, real growth rate and nominal interest rate. We find that the slope of the curve in Japan is positive in almost all periods since the 1990s. In addition, looking at the estimated inflation expectations in time series, the inflation expectations at all horizons rose in the mid-2000s and from late 2012 to 2013, after the downward trend from the early 1990s to the early 2000s. Short-term inflation expectations in particular have tended to shift upwards since the launch of Quantitative and Qualitative Monetary Easing, while being affected by fluctuations in the import price. Finally, a structural VAR analysis shows that the estimated inflation expectations in Japan are largely adaptive, meaning their formation is affected by actual inflation rates.

Keywords: Inflation expectations; Term structure; State-space model
JEL classifications: C32; D84; E31; E43; E52

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1. Introduction

The inflation expectations of private agents play a key role in price developments, and as such, economists around the world have made considerable efforts to measure inflation expectations. Inflation expectations exhibit non-negligible heterogeneity because of the wide range of respondents in the data – households, firms and experts. In addition, forecast horizons are different among the data, from short term to long term.

Most central banks assess underlying inflation expectations in the whole economy by cross-checking inflation forecasts of various agents and those at different horizons (ECB (2006)).[1] To support these assessments, some central banks try to extract the underlying inflation expectations from the various forecast data using statistical methods, accepting the heterogeneity among agents in forming expectations as given. As an example, Bank of Japan (2016) and Nishino *et al*. (2016) build their "synthesized inflation expectation indicators (SIEI)" using principal component analysis with the inflation forecasts of households, firms and experts.

Since the global financial crisis of 2008, interest in the "inflation expectations curve" – a term structure of inflation expectations – has also been growing, mainly in the U.S. This reflects the fact that advanced economies have faced long-lasting low inflation – missing inflation – during the economic recovery since the global financial crisis. This makes it all the more important for central banks to know when people's expected inflation rates will come close to the inflation targets set by the central banks. For instance, the Federal Reserve Bank of Philadelphia releases a monthly inflation expectations curve, based on Aruoba (2016), which uses the Nelson-Siegel model to combine a number of the inflation forecasts of experts. Crump, Eusepi, and Moench (2018) estimate another inflation expectations curve, combining various forecast data on the inflation rate of experts, as well as forecasts on the real growth rate and the nominal interest rate, which could influence the inflation rate. They use a state-space model assuming theoretical relationships among these three variables.

Based on this research into inflation expectations, we combine the forecast data of various agents to estimate an inflation expectations curve for Japan. In order to cross-check a variety of forecast data, we build a large dataset which includes survey-based forecasts of various agents – households, firms, and experts, in addition to market-based forecasts. Putting the dataset in a state-space model building on Crump,

[1] The Federal Reserve Board also uses multiple types of forecasts to assess inflation expectations. The FRB said in its FOMC statement in March 2019, "On balance, market-based measures of inflation compensation have remained low in recent months, and survey-based measures of longer-term inflation expectations are little changed."

Eusepi, and Moench (2018) with some modifications, we estimate a term structure of inflation expectations. To the best of our knowledge, this paper is the first to estimate the term structure of inflation expectations in Japan combining various forecast data.

The findings of this paper are summarized by the following points: First, the slope of the curve is positive in almost all periods since the 1990s, which is similar to the results of previous studies in the U.S. Second, after the downward trend from the early 1990s to the early 2000s, the inflation expectations at all horizons rose in the mid-2000s and from late 2012 to 2013. Third, short-term inflation expectations in particular have tended to shift upwards since the launch of Quantitative and Qualitative Monetary Easing (QQE), while being affected by fluctuations in the import price. Finally, we find that inflation expectations are largely adaptive. Our structural VAR analysis shows that inflation expectations react to a positive shock to the actual inflation rate, which is statistically significant, and its influence lasts over a relatively long period. It also shows that long-term inflation expectations react more gradually than short-term inflation expectations.

The remainder of this paper is organized as follows: Section 2 summarizes related literature and describes the characteristics of this paper. In section 3 we show the data for estimation. Section 4 presents our model. Section 5 shows the estimated inflation expectations curve in Japan. Section 6 devotes space to an analysis of the characteristics of the curve. Section 7 concludes.

2. Related Literature and Characteristics of This Paper

Research on inflation expectations has progressed remarkably in recent years.[2] In this section, we summarize the literature on inflation expectations which relates closely to this paper in terms of two points: literature on heterogeneity among agents in forming inflation expectations, and literature on the term structure of inflation expectations. We then describe the characteristics of this paper, comparing it to these strands of the literature.

2.1. Heterogeneity in Forming Inflation Expectations

Recent microdata analyses of survey data have shown that there is heterogeneity among agents – households, firms and experts, in forming inflation expectations. For instance,

[2] Coibion, Gorodnichenko and Kamdar (2018) summarize recent progress in the field.

Coibion *et al.* (2018) claim that experts' inflation expectations are more responsive to changes in monetary policy than those of households and firms. On the other hand, Cavallo, Cruces, and Perez-Truglia (2017) find that households form inflation expectations that reflect their daily purchasing experience. Coibion, Gorodnichenko and Kumar (2018) demonstrate that firms care more about their competitors' prices than aggregate price when forming their inflation expectations.

In addition, it has been shown that market-based forecasts have different characteristics from those of survey-based forecasts. For example, Christensen, Dion, and Reid (2004) and Haubrich, Pennacchi, and Ritchken (2012) point out that the break-even inflation rate (BEI) obtained from Treasury Inflation-Protected Securities, which reflects the inflation expectations of market participants, is influenced by inflation-risk premia and liquidity premia. During the global financial crisis in particular, the BEI level was far below normal due to the rapid decline of liquidity in the bond market.

There is no consensus on whose expectations a central bank should monitor. Burke and Ozdagli (2013) argue that the inflation expectations of households are particularly important, since households' expectations directly affect consumption via changes in the real interest rate. On the other hand, Coibion and Gorodnichenko (2015) argue for the importance of firms' inflation expectations, since firms set their prices based on their expectations in the New-Keynesian Model, a popular macroeconomic model among academics.

While there is literature that points out the heterogeneity among various agents' expectations, some literature suggests that the expectations of different agents are related to each other. Carroll (2003) demonstrates that households and firms refer to experts' inflation expectations when forming their own expectations. In addition, Bullard (2016) points that households' inflation expectations influence consumer prices as they affect firms' price setting through wage negotiations. Coibion, Gorodnichenko, and Kamdar (2018) argue that if firms' inflation expectations are influenced by experts' and households' expectations, as the literature above claims, there would be justification for using households' and experts' inflation expectations to estimate the Phillips curve, which is originally derived from firms' price-setting behavior. These strands of research suggest that the inflation expectations of various agents are not entirely heterogeneous and they have common components. Bank of Japan (2016) and Nishino *et al*. (2016) take these common components into account when building their SIEI, combining the inflation forecast data of three types of agents – households, firms, and experts, using principal component analysis. They use the indicators to analyze underlying inflation expectations in the whole economy, dividing their movements into several phases.

2.2. Inflation Expectations Curve

Next, we summarize the existing literature on the term structure of inflation expectations using inflation forecast data at various horizons. As noted on the website of the Federal Reserve Bank of Philadelphia,[3] the available inflation forecast horizons are limited in general and their data points are widely spaced. Therefore, one issue is how to connect these non-contiguous forecasts in order to estimate a contiguous term structure of inflation expectations.

One way to connect these forecasts is to apply the term structure models of interest rates developed in finance literature. Some studies use an affine term structure model. For example, Chernov and Mueller (2012) use several survey-based forecasts such as the Livingston Survey, the Survey of Professional Forecasters (SPF), and Blue Chip to estimate their inflation expectations curve in the U.S. Haubrich, Pennacchi, and Ritchken (2012) also use SPF and Blue Chip as survey-based forecasts, and inflation swap rates as market-based forecasts, to estimate their inflation expectations curve in the U.S. In contrast to these papers, other research uses the Nelson-Siegel model. Aruoba (2016) uses the Nelson-Siegel model to estimate his inflation expectations curve, using multiple horizons of two surveys, SPF and Blue Chip, for CPI inflation forecasts in the U.S. This inflation expectations curve, which covers inflation expectations at any horizon from 3-months ahead to 10-years ahead, is updated monthly and published on the website of the Federal Reserve Bank of Philadelphia as the ATSIX (Aruoba Term Structure of Inflation Expectations).[4]

Another way is to build a state-space model, incorporating the ideas of macroeconomics into the model. For example, Kozicki and Tinsley (2012) apply a state-space model incorporating the Beveridge-Nelson decomposition, and they estimate a term structure of inflation expectations in the U.S. using short-term inflation forecasts in the Livingston Survey. According to them, the forecast horizons in many survey-based forecasts on inflation rate are limited to the short term. Therefore, a model which can connect short-term and long-term expectations is required to obtain long-term inflation expectations. To this end, they claim that estimating a state-space model in which inflation expectations are decomposed into trend components and cyclical components gives the ability to extract the movement of long-term inflation

[3] See https://www.philadelphiafed.org/research-and-data/real-time-center/atsix.
[4] For details of the ATSIX, see footnote 3.

expectations. Mehrota and Yetman (2018) assume a similar model structure to estimate a term structure of inflation expectations in the U.S. While Kozicki and Tinsley (2012) use a single survey-based forecast with two horizons, Crump, Eusepi, and Moench (2018) expand their method to a large dataset with more than 600 survey-based forecasts, to estimate their inflation expectations curve in the U.S.[5] Furthermore, they use survey-based forecasts on real growth rate and nominal interest rate as well, assuming that in the long term there is a standard macroeconomic relationship between them – the Fisher equation.[6]

The literature mentioned above suggests that inflation expectations curves in the U.S. have two features: First, the slope of the curve is positive in almost all sample periods. Second, long-run inflation expectations have been by and large stabilized in the lower 2% range since the 2000s.

2.3. Characteristics of Our Paper

This paper estimates the inflation expectations curve in Japan based on Crump, Eusepi, and Moench (2018) with several modifications. Below are the characteristics of our paper which differ from the previous literature.

First, we estimate the underlying inflation expectations in the whole economy, assuming there exists a common component among forecasts of various agents, while allowing for heterogeneity in inflation expectations. This idea is the same as that of the synthesized inflation expectation indicators (SIEI), in Bank of Japan (2016) and Nishino *et al.* (2016), which incorporate the inflation forecasts of households, firms and experts. One main difference between these papers and ours is in the term structure of the model. The SIEI is extracted as a first principal component of three forecast data ignoring the term structure of individual data. Compared with the SIEI, we estimate underlying inflation expectations using a model which considers consistency among forecast data at different horizons and for relationships between inflation rate, real growth and nominal interest rate.

Second, previous literature on inflation expectations curves uses survey-based forecasts of experts or market-based forecasts to estimate the term structure. In our research, we use surveys of households and of firms as well to combine information of

[5] In detail, the following surveys are used: *Blue Chip Economic Indicators*, *Blue Chip Financial Forecasts*, *Consensus Forecasts*, *Decision-Makers' Poll*, *Economic Forecasts: A Worldwide Survey*, *Goldsmith-Nagan Survey*, *Livingston Survey*, *Survey of Primary Dealers* and *SPF*.

[6] For details, see section 4. We also assume a VAR-based relationship among the cyclical components of these three variables.

forecasts from various agents.

Third, technically, while previous literature uses the maximum likelihood estimation (MLE), we use a Bayesian estimation for our inflation expectations curve. It is known that the values of estimated parameters in the MLE are not necessarily stable if a model structure is complex with many parameters. Using a Bayesian method could mitigate this issue.

3. Data

In this section we describe the data used for our estimation. In addition to inflation forecasts, we also use forecasts on the real growth rate and nominal interest rate, because these forecasts can provide information on inflation expectations. Actual data for these variables are also included as a starting point for the inflation expectations curve. For details of the data used, see Appendix 1.

Regarding inflation forecasts, we use survey-based forecasts of households, firms, and experts, in addition to market-based forecasts.[7] For experts, we use six data series from *Consensus Forecasts*,[8] one from *Blue Chip*, two from *Quick Monthly Market Survey*, and three from *ESP Forecast*. For firms, we use three from *Tankan (Inflation Outlook of Enterprises)* and one from *QUICK Tankan*. For households, we use one from *Opinion Survey on the General Public's Views and Behavior*. For market-based forecasts, one from *Inflation Swap Rate* and one from *Break-Even Inflation Rate* are used. In total, we use 19 forecasts (Figure 1).

As for forecast data on the real growth rate, the number of available forecast data in Japan is limited and all of them are of experts. We use six from *Consensus Forecasts*, one from *Blue Chip* and three from *ESP Forecast*. The total number of forecasts is 10 (Figure 2). Finally, for forecast data on the nominal interest rate, we use market-based forecasts, since survey-based forecasts for more than 1-year ahead on the 3-month T-bill rate, used as the nominal interest rate in our model, are not available. From the spot rates for 1-year, 2-year, … , 10-year nominal interest rates for government bonds, we calculate the forward rate for 1y-1y (1-year, 1 year forward), 2y-1y,…, 9y-1y and use these nine data series as forecasts for the nominal interest rate.

In addition, as actual data, we use the CPI (less fresh food, seasonally-adjusted

[7] For details of how the inflation forecasts are adjusted for changes in the consumption tax rate, see Appendix 1.

[8] If a survey asks forecasters for several horizons, e.g., 1-year, 2-years, 3-years, 4-years, 5-years, and 6 to 10 years ahead in *Consensus Forecasts*, all of these forecasts are treated separately in our model. The number of forecasts used from *Consensus Forecasts* is therefore six.

quarter-over-quarter change, adjusted for changes in the consumption tax rate), real growth rate (seasonally-adjusted quarter-over-quarter change), and 3-month T-bill rate (Figure 3). We also use the import price index (IPI, quarter-over-quarter change) as an exogenous variable, which would influence the inflation rate in the model. All data are compiled on a quarterly basis for estimation.

As a result, we use a total of 42 indicators in this model: 38 forecasts, and 4 actual data.[9] Our dataset includes almost all available survey-based forecasts and market-based forecasts on inflation rate, real growth rate and nominal interest rate in Japan.[10] The number of series in our dataset is smaller than that in Crump, Eusepi, and Moench (2018), which uses about 600 indicators. This reflects the fact that there is a large difference between the U.S. and Japan in the number of forecasts available.

When using these forecasts, one issue is whether we should use the "spot-rate type" or the "forward-rate type." In the former type, the forecast horizon starts from the current date and represents the average growth rate over h years, while in the latter, the forecast horizon starts from a future date and represents one-year growth (or multi-year growth) starting from that future date.[11] In this paper all of the spot-rate type forecast data are transformed to the forward-rate type, since it is desirable to obtain information on each term separately to estimate a term structure. For instance, in the *QUICK Monthly Market Survey*, three spot-rate type forecasts are available: average annualized inflation rate over the next 1 year, next 2 years, and next 10 years. Using the first two indicators, we calculate inflation forecasts from 1-year ahead to 2-years ahead (in short, 1y-1y). Similarly, the last two indexes allow us to obtain inflation forecasts from 2-years ahead to 10-years ahead (in short, 2y-8y). These two transformed forward-rate type forecasts are used in our model.

4. Model Structure and Estimation

4.1. Model Structure

As noted in section 2, we estimate the inflation expectations curve in Japan using the state-space model in Crump, Eusepi, and Moench (2018) with some modifications. A

[9] In addition to these indicators, we use potential growth rate (year-over-year change). See section 4.1 for details.

[10] For estimation, we use data in which forecast horizons are not basically less than 1 year. This means, for example, a survey for 6-months ahead is not used in our research.

[11] In the terminology of nominal interest, the former is equivalent to the spot rate and the latter is equivalent to the forward rate. Therefore, we call the former "spot-rate type" and the latter "forward-rate type."

state-space model is structured on two types of equations: "state equations," which show the dynamics of state variables in the model; and "observation (or measurement) equations," which represent the relationships between observed variables and state variables.

First, we consider the structure of state equations. Like Crump, Eusepi, and Moench (2018), z_t is the vector of three state variables in our model, inflation rate (π_t), real growth rate (g_t), and nominal interest rate (i_t). These are all assumed to be decomposed into trend components and cyclical components, following the Beveridge-Nelson decomposition.[12] In equation (1), $\bar{z}_t$ is the vector of trend components and $\hat{z}_t$ is the vector of cyclical components. In the formation of expectation values at each horizon from actual values, we assume that trend and cyclical components follow different dynamics.

$$\begin{gathered} z_t = (g_t\,, \pi_t\,, i_t)' \\ z_t = \bar{z}_t + \hat{z}_t. \end{gathered} \tag{1}$$

The dynamics of the trend components are described in equations (2) and (3). Equation (2) represents the dynamics of the trend inflation rate $(\bar{\pi}_t)$ and trend real growth rate $(\bar{g}_t)$, which are assumed to follow the multivariate random walk, as in Stock and Watson (2007).[13] Here, shocks $\eta_{\bar{\pi},t}$ and $\eta_{\bar{g},t}$ are mean-zero, i.i.d., mutually independent Gaussian innovations. The third element of the trend components, nominal trend interest rate, $(\bar{\imath}_t)$, is a linear function of the other two trend components via the Fisher equation in equation (3). Residual error $(\bar{\varsigma}_t)$ follows an independent random walk, and shock in the process $(\eta_{\bar{\imath},t})$ is assumed to follow a mean-zero, i.i.d., mutually independent Gaussian innovation.[14,15]

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[12] See Beveridge and Nelson (1981). Takahashi (2016) also uses this decomposition. He estimates trend inflation in Japan as the weighted average of trend components only of the actual inflation rate and super long-term inflation rate expectations.

[13] By assuming that the trend inflation rate follows a random walk process, I(1), we potentially allow the trend inflation rate to change permanently in the sample period, which reflects the change in recognition of private agents. An example is the change in recognition regarding the central bank's inflation target. Under this assumption, the trend inflation rate could diverge. However, as shown in section 5 below, our estimated long-term inflation expectations do not diverge and remain within the range of other inflation expectations estimated by different methods.

[14] The original version of the Fisher equation is that the nominal interest rate is equal to the sum of the real interest rate and inflation expectations. Crump, Eusepi, and Moench (2018) derive equation (3) by assuming that ψ, the inverse of the intertemporal elasticity of substitution, links the real interest rate to the trend real growth rate of the economy, which emerges commonly from dynamic general equilibrium models. They claim that the residual error in the equation captures changes in household preferences and other determinants of $\bar{\imath}_t$.

$$\begin{pmatrix}\bar{g}_t\\ \bar{\pi}_t\end{pmatrix} = \begin{pmatrix}\bar{g}_{t-1}\\ \bar{\pi}_{t-1}\end{pmatrix} + \begin{pmatrix}\eta_{\bar{g},t}\\ \eta_{\bar{\pi},t}\end{pmatrix}, \tag{2}$$

$$\bar{\imath}_t = \psi\bar{g}_t + \bar{\pi}_t + \bar{\varsigma}_t, \quad \bar{\varsigma}_t = \bar{\varsigma}_{t-1} + \eta_{\bar{\imath},t}. \tag{3}$$

On the other hand, the cyclical components are assumed to evolve following a vector auto-regression (VAR) structure. That is, the three elements, $\hat{g}_t$, $\hat{\pi}_t$, and $\hat{\imath}_t$ affect each other with lags. In addition, we add two modifications to the model in Crump, Eusepi, and Moench (2018). First, the import price index (IPI) is added to the model as an exogenous variable.[16] Here, IPI is assumed to follow AR(2). Second, while Crump, Eusepi, and Moench (2018) choose VAR(1) as the structure of dynamics of cyclical components, we choose VAR(3), as it maximizes the marginal likelihood in the whole model.[17,18] Therefore, the dynamics of the cyclical components are four-variable VAR(3) as in equation (4). Here, Φ_k $(k = 1, 2, 3)$ is a transition matrix which shows the dynamic relationships between these four variables. ν_t represents the vector of shocks to the variables, in which each shock is a mean-zero, i.i.d., mutually independent Gaussian innovation. The shocks are identified by the Cholesky decomposition in the following order: real growth rate comes first, which is assumed to be affected only by its own shock $\left(\varepsilon_{\hat{g}_t}\right)$; inflation rate comes next, which is assumed to be affected by real growth rate shock in addition to its own shock $\left(\varepsilon_{\hat{\pi}_t}\right)$; finally, nominal interest rate comes last, which is assumed to be affected by both real growth rate shock and inflation rate shock in addition to its own shock $\left(\varepsilon_{\hat{\imath}_t}\right)$.

[15] To assume that this type of Fisher equation is consistent among the three trend components, it is implied that a representative consumer's utility function is linearly approximated. It is also implied that two parameters, the inverse of the intertemporal elasticity of substitution and relative risk aversion, must be equal in the function. An alternative idea is to modify the utility function to Epstein-Zin recursive preferences (Epstein and Zin (1989) and Kano and Wada (2017)). This is expected to show how uncertainty among households would affect inflation expectations in assuming the utility function.

[16] The import price index is taken to include information on various prices comprehensively, such as energy price and exchange rate.

[17] Marginal likelihood is obtained by taking integral of products of likelihood functions and prior distributions of parameters. In this paper, we use the modified harmonic mean estimator by Geweke (1999) as marginal likelihood.

[18] We choose the number of own lags of IPI based on the same criteria.

$$\begin{pmatrix} \hat{z}_t \\ IPI_t \end{pmatrix} = \Phi_1 \begin{pmatrix} \hat{z}_{t-1} \\ IPI_{t-1} \end{pmatrix} + \Phi_2 \begin{pmatrix} \hat{z}_{t-2} \\ IPI_{t-2} \end{pmatrix} + \Phi_3 \begin{pmatrix} \hat{z}_{t-3} \\ IPI_{t-3} \end{pmatrix} + \nu_t$$

$$\Phi_1 = \begin{bmatrix} b_1 & b_2 & b_3 & b_4 \\ b_5 & b_6 & b_7 & b_8 \\ b_9 & b_{10} & b_{11} & b_{12} \\ 0 & 0 & 0 & b_{37} \end{bmatrix}, \qquad \Phi_2 = \begin{bmatrix} b_{13} & b_{14} & b_{15} & b_{16} \\ b_{17} & b_{18} & b_{19} & b_{20} \\ b_{21} & b_{22} & b_{23} & b_{24} \\ 0 & 0 & 0 & b_{38} \end{bmatrix}, \tag{4}$$

$$\Phi_3 = \begin{bmatrix} b_{25} & b_{26} & b_{27} & b_{28} \\ b_{29} & b_{30} & b_{31} & b_{32} \\ b_{33} & b_{34} & b_{35} & b_{36} \\ 0 & 0 & 0 & 0 \end{bmatrix}, \qquad \nu_t = \begin{bmatrix} \varepsilon_{\hat{g}_t} \\ \varepsilon_{\hat{\pi}_t} + b_{39}\varepsilon_{\hat{g}_t} \\ \varepsilon_{\hat{i}_t} + b_{40}\varepsilon_{\hat{g}_t} + b_{41}\varepsilon_{\hat{\pi}_t} \\ \varepsilon_{IPI_t} \end{bmatrix}$$

$b_1, \ldots, b_{41}$ are parameters estimated in the model.

As shown above, based on the assumption that different mechanisms work for the dynamics of trends and cyclical components – the Fisher equation for trend components and a VAR structure for cyclical components – we connect the expectation values of inflation rate, real growth rate and nominal interest rate.

We next consider the observation equations in this model. In equation (5), y_t is a 43×1 vector of observed data. Of those, y_t^F, a 38×1, vector includes forecasts on inflation rate, real growth rate and nominal interest rate at time *t*, while y_t^A, a 5×1 vector, contains the actual values of these variables, IPI and potential growth rate. Note, throughout this paper, we let a superscript "A" or "F" denote variables related to actual or forecast data, respectively. Here, to reduce the number of estimated parameters, we use the potential growth rate estimated by the Research and Statistics Department at the Bank of Japan as observed data of trend components of real growth rate.[19] H_t is a 43×18 matrix of parameters which connects observed variables and state variables in this model.[20] H_t^F is a 38×18 matrix connecting forecast data and state variables, while H_t^A is a 5×18 matrix connecting actual data and state variables. Z_t is an 18×1 vector which contains state variables, their lag components,[21] trend components $\bar{z}_t$, and cyclical components $\hat{z}_t$. ε_t is a 43×1 matrix for the observation errors. ε_t^F is a 38×1 vector for the observation errors of forecasts, which are mean-zero, i.i.d., mutually independent Gaussian innovations.[22] Unlike Crump, Eusepi, and Moench (2018), who

[19] For details of this potential growth rate, see Kawamoto *et al.* (2017).

[20] For details of each vector, see Appendix 3.

[21] The lag components of z_t, $(z_{t-1}, z_{t-2}, z_{t-3})$ are used in the observation equation to convert forecast data from the year-over-year change (annualized) in the original data to the quarter-over-quarter change for the model. For details of conversion method, see Appendix 3 in this paper, Appendix A.3 in Crump, Eusepi, and Moench (2018), and Crump *et al.* (2014).

[22] It cannot be denied *a priori* that the observation errors do not follow the i.i.d. process. In addition,

assume that standard deviations of the observation errors of different forecasts at close horizons are equal, we assume that all of them can be different. In addition, we assume that all components of ε_t^A, 5×1, are zero, which implies that there are no observation errors in the actual data.

$$
\begin{gathered}
y_t = H_t Z_t + \varepsilon_t \\
y_t = \begin{pmatrix} y_t^F \\ y_t^A \end{pmatrix}, \quad H_t = \begin{pmatrix} H_t^F \\ H_t^A \end{pmatrix}, \quad \varepsilon_t = \begin{pmatrix} \varepsilon_t^F \\ 0 \end{pmatrix} \\
Z_t = (z_t\, , z_{t-1}\, , z_{t-2}\, , z_{t-3}\, , \overline{z}_t\, , \widehat{z}_t)'
\end{gathered}
\tag{5}
$$

It is worth noting that we assume the structure of H_t^F is the same for two different forecasts at the same horizon. This means that the difference in the value between two forecasts is explained in the observation errors, ε_t^F. Regarding this point, we extract a part of equation (5) into equation (6). In the left-hand side of the equations, $y_{t,t+k}^{F1}$ and $y_{t,t+k}^{F2}$ are the observed values of two forecast data, "Forecast 1" and "Forecast 2." Both are inflation forecasts for k-periods ahead at time t. The values in the two forecasts could be different, but as $H_{t+k}^F Z_t$ in the right-hand side is common to both equations, the difference appears in the observation errors, $\varepsilon_{t,t+k}^{F1}$ and $\varepsilon_{t,t+k}^{F2}$. Therefore, the state variable, $E_t \pi_{t+k}$, the inflation expectation for k-periods ahead at time t, is interpreted as the common component of expectations, excluding heterogeneity.

$$
\begin{aligned}
y_{t,t+k}^{F1} &= H_{t+k}^F Z_t + \varepsilon_{t,t+k}^{F1} \\
y_{t,t+k}^{F2} &= H_{t+k}^F Z_t + \varepsilon_{t,t+k}^{F2}.
\end{aligned}
\tag{6}
$$

In the following, we estimate the inflation expectations curve using this model.

4.2. Estimation Method: Bayesian Estimation

Previous research using a state-space model estimates the model with maximum likelihood estimation (MLE). In the MLE method, a Kalman filter is used to derive the likelihood function, and a set of parameters which maximizes the value of the function is estimated. It is commonly used for estimation in state-space models.

In estimating their model, Crump, Eusepi, and Moench (2018) first divide forecasts

considering that Japan has been under the zero lower bound of nominal interest rates for a long time, it may not necessarily be appropriate to assume normal distributions on observed errors of the forecasts of nominal interest rates over the entire period of estimation. One possible modification is to allow that non-linearity exists in nominal interest rates and that distributions are time-varying. Both of these points are, however, not discussed in this paper.

for all variables into three groups, short-term, medium-term, and long-term forecasts, based on their forecast horizons. They next assume that the standard deviations of observation errors in the same group are equal, which greatly reduces the number of standard deviations to be estimated. This assumption can be justified only when using the forecast data of experts. In contrast, we use the survey-based forecasts of various agents – households, firms, and experts, in addition to market-based forecasts. This suggests that heterogeneity among forecasts in our dataset is larger than in Crump, Eusepi, and Moench (2018), which implies that it may not necessarily be appropriate to apply their assumption to our model. Therefore, we assume that all of standard deviations of observation errors of forecasts are different. In addition, while Crump, Eusepi, and Moench (2018) assume a VAR(1) structure for the cyclical components in their model, our model uses a VAR(3) structure. Therefore, the number of parameters to be estimated in our model is larger than that in Crump, Eusepi, and Moench (2018). It is practically known that the estimated results of a model with a lot of parameters in the MLE method could be unstable, since the shape of the likelihood function in the model can be quite complex.

We therefore adopt a Bayesian method in the estimation of our model. In using a Bayesian estimation, we multiply an estimated likelihood function by a prior probability distribution of each parameter to calculate numerically a posterior probability distribution. This method is helpful in estimating a model with a number of parameters, since we can identify the value of these parameters under a Bayesian estimation no matter how complex the structure of the likelihood function is.

When using a Bayesian estimation, the shape of prior distribution could have some effect on the estimated values. The estimated inflation expectations curve tends to more (or less) reflect a forecast in the cases where we set a smaller (or larger) mean in the prior distribution of standard deviation of an observation error of the forecast. In this paper we therefore eliminate any arbitrariness by applying some rules mechanically in setting prior distribution. Details are given in Appendix 2. In a nutshell, we set prior distributions in order that all horizons (short-, medium- and long-term) and types of agents (households, firms, and experts), are well-balanced *ex ante*. We employ a random walk Metropolis-Hastings (M-H) algorithm in our estimation.[23]

[23] In the random walk M-H algorithm, samples are drawn so that the difference between their values and those of previous samples is small. This implies that samples can be selected only around the local mode of the posterior distribution. Regarding this point, we run several estimations starting from different sets of initial values given prior distributions and check that the estimated posterior distributions are almost the same in all cases. Convergence of parameters is checked by the method of Brooks and Gelman (1998). In sampling, 300,000 draws are generated and first half of them are burned-in.

We estimate the inflation expectations curve from 1989/4Q to 2018/3Q. The sample period, about 30 years, is based on the periods available in *Consensus Forecasts*, the longest survey in our dataset. One practical advantage of a state-space model is, as Kozicki and Tinsley (2012) claim, that we can estimate the curve even if some figures are missing from the surveys, because of the Kalman filter in a state-space model. In fact, in our dataset, some forecasts started quite recently, and other surveys release data infrequently, for example semiannually rather than quarterly. Even under these restrictions, we can estimate inflation expectations curves in long time series.[24]

5. Estimation Result

5.1. Inflation Expectations Curve in Japan

In this subsection we show the inflation expectations curve in Japan based on the data in section 3 and on the estimation method in section 4. Figure 4(1) shows the actual CPI inflation rate (purple line) and inflation expectations curve (gray lines) since 1990. The inflation expectations in Figure 4(1) are the expectations up to 10-years ahead in the first quarter of each year.

The slope of the curve is positive in almost all sample periods. This result is similar to the U.S. inflation expectations curves estimated by Aruoba (2016) and Crump, Eusepi, and Moench (2018). In addition, as the term becomes longer, the slope of the curve gradually flattens and converges at a particular value. This is due to the structure of the Beveridge-Nelson decomposition: inflation expectations are divided into a trend component and a cyclical component, and as the term increases, the influence of the cyclical components disappears and inflation expectations converge to the trend component.

In Figure 4(2), short-term (the average of 1-year and 2-years ahead), medium-term (the average of 3-years and 4-years ahead), and long-term (the average from 5-years to 10-years ahead) expectations are shown.[25] Looking at these inflation expectations in time series, the expectations gradually declined from the early 1990s to the early 2000s for all terms (short, medium, and long).[26] After that, these expectations rose in the

[24] Regarding the SIEI, the starting point of the estimation is restricted to that of the "shortest" survey, as principal component analysis needs all the data to extract the first principal component. Compared with the SIEI, therefore, our method can estimate inflation expectations in longer time series.

[25] The criteria for the grouping are based on Crump, Eusepi, and Moench (2018). We use the same criteria when grouping observation errors (see Appendix 2).

[26] In the early 2000s, the actual inflation rate remained below 0% and the level of inflation expectations became the lowest. However, even at that time, the slope of the inflation expectations

mid-2000s and from late 2012 to 2013. The rise in the mid-2000s was likely affected by the fact that the consumer price developed from a declining phase to being flat and then turned to a phase of gradual rise, under economic expansion and a rising trend in import prices. With regard to the rise from late 2012 to 2013, as Bank of Japan (2016) and Nishino *et al.* (2016) claim, the introduction of the price stability target and the launch of QQE is considered to have had a positive effect on the rise from late 2012 to 2013. Short-term inflation expectations in particular have tended to shift upwards since the launch of QQE, while being affected by fluctuations in the import price. Even when the actual inflation rate fell below 0% due to the decline in oil prices, short-term inflation expectations stabilized around 0.5%. This observation implies that short-term inflation expectations have become less susceptible to decline due to temporary factors.

5.2. Comparison with Existing Indicators on Inflation Expectations in Japan

In this subsection, we compare the estimated short-term, medium-term, and long-term inflation expectations to existing inflation expectation indicators and describe the features of inflation expectations in our model.

In Figure 5(1), we compare the short-term, medium-term, and long-term inflation expectations in our model with the synthesized inflation expectation indicators (SIEI) based on Bank of Japan (2016) and Nishino *et al.* (2016). As we mentioned above, the characteristic these two indicators have in common is that they both combine the inflation forecasts of various agents – households, firms, and experts – to capture the underlying inflation expectations in the whole economy. Comparing the SIEI with our inflation expectations, the SIEI moves between the short term and the medium term of our inflation expectations. This result would reflect the fact that the simple average forecast horizons of the data used in the SIEI are between the short term and the medium term in our estimation, though there are caveats in rigorous comparison between SIEI and our series due to the difference in the estimation method.[27]

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curve was positive and long-term inflation expectations were just below 1%. Such observations suggest that people expected the inflation rate to increase gradually in the long run. This is consistent with several estimated long-term inflation expectations in Japan in Nishizaki, Sekine and Ueno (2014).

[27] In the SIEI, *Opinion Survey on the General Public's Views and Behavior* (5 years ahead) is used for households' expectations, *Tankan* (D.I. on 'Change in Outlook Prices') is for firms' expectations, and each of (i) *Consensus Forecasts* (from 6 to 10 years ahead) or (ii) *QUICK Monthly Market Survey* (10 years) or (iii) *Inflation Swap Rate* (5y-5y) is used for experts' expectations. Therefore, there are three estimated indicators in which forecasts for experts are different.

In Figure 5(2), we next compare our estimation result to two long-term inflation expectation indicators in existing studies: "trend inflation" in Kaihatsu and Nakajima (2015), and "long-term inflation expectations" in Hogen and Okuma (2018). Compared with the trend inflation in Kaihatsu and Nakajima (2015), our long-term inflation expectations are clearly higher. This reflects the data used for the estimation: Kaihatsu and Nakajima (2015) estimate trend inflation based only on actual data, such as the inflation rate, while we incorporate a large amount of forecast data as well. In other words, our indicators reflect the fact that medium- and long-term inflation forecasts tend to be higher than the actual inflation rate. Compared with Hogen and Okuma (2018), the levels of the indicators are different in some periods, for example in the 2000s. The gap between the two indicators seems to stem from the differences in mechanism and data. Hogen and Okuma (2018) assume a learning mechanism in forming expectations, where forecast errors of short-term inflation expectations lead to a change in long-term inflation expectations. They therefore do not use data on medium- and long-term inflation forecasts. On the other hand, we impose a reduced form mechanism in the state-space model and use data on medium- and long-term inflation forecasts as well. Even with this difference, the two indicators tend to be quite similar in the 1990s and after the launch of QQE, when gaps between short-term and long-term inflation expectations in our model are relatively small.

6. VAR Analysis: Response to a Shock to the Actual Inflation Rate

In this section we provide an empirical analysis of the characteristics of the estimated inflation expectations curve. Recent research on inflation expectations suggests that inflation expectations consist of two components: the forward-looking component and the backward-looking (or adaptive) component. Previous studies show that inflation expectations in Japan are largely adaptive, and thus more influenced by the movement of the actual inflation rate than in the U.S. (Bank of Japan (2016) and Nishino *et al.* (2016)). In this section we analyze whether this claim is observed in our inflation expectations which consider a combination of forecasts of various types of agents and term structure.

We use a vector auto-regression (VAR) consisting of three variables: the actual inflation rate, short-term inflation expectations, and long-term inflation expectations. We check the impulse responses of these two expectation series to a 1 percentage point increase shock to the actual inflation rate.

The impulse responses in Figure 6 show that short-term inflation expectations react quickly to a 1 percentage point (annualized) increase shock to the actual inflation rate, and the effect decays after it reaches the peak at the level of between 0.1 percentage point and 0.2 percentage point. On the contrary, long-term inflation expectations react more slowly to the same shock, and the magnitude of the response, around 0.1 percentage point, is smaller than that of the short term. In addition, the influence of the shock remains on both expectation series after twelve quarters, which is statistically significant.[28]

This result supports the argument that inflation expectations are largely adaptive in Japan. Bank of Japan (2018) estimates a similar VAR in which inflation forecasts for 1-year ahead and for 6 to 10 years ahead by *Consensus Forecasts* are used as short-term and long-term inflation expectations, respectively. The result of our research is quite similar to that of the Bank's research, which implies that the estimation result in Bank of Japan (2018) is robust in considering a combination of forecasts of various types of agents and term structure.

7. Concluding Remarks

In this paper we estimate the "inflation expectations curve" as a term structure of inflation expectations in Japan, based on the idea of Crump, Eusepi, and Moench (2018) with some modifications. The two main features of our research are as follows: First, we combine the information of the forecasts of various agents comprehensively to estimate the underlying inflation expectations in the whole economy, accepting the heterogeneity among agents in forming expectations as given. Second, using a state-space model, we estimate a term structure of inflation expectations with consistency between horizons from short term to long term.

The results from our analysis are summarized in the following four points: First, we find that the slope of the curve is positive in almost all periods since the 1990s. Second, after the downward trend from the early 1990s to the early 2000s, the inflation expectations at all horizons rose in the mid-2000s and from late 2012 to 2013. Third, short-term inflation expectations in particular have tended to shift upwards since the launch of QQE, while being affected by fluctuations in the import price. Finally, a structural VAR analysis which gauges the effect of the shocks to actual inflation on short-term and long-term inflation expectations shows that inflation expectations in Japan are largely adaptive.

[28] In the VAR model in this section we assume a certain order in the shocks between actual inflation and inflation expectations. See Figure 6 for details.

A future agenda would be to build a more structural model incorporating the formation mechanism of inflation expectations. Our model assumes a reduced-form mechanism which is convenient to reflect forecast data, therefore we do not assume any structure on the formation mechanism of inflation expectations. Recent research argues that primary factors in forming inflation expectations are different between short-term and long-term inflation expectations (Fuhrer (2012, 2017)). To estimate a more elaborate term structure of inflation expectations, incorporating those results on formation mechanism, is left as a future research agenda.

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Appendix 1. Data

Below are details of the data employed in estimating the inflation expectations curve.

(i) Forecast data

[*Consensus Forecasts*] (Experts, on Inflation rate and Real growth rate)

Conducted quarterly by Consensus Economics. Part of the forecasts are conducted monthly. Data are from 1989/4Q, while data up through April 2014 are compiled semi-annually. 6 indicators (1y, 2y 3y, 4y, 5y and 6 to 10y ahead) are used. They are adjusted by the authors of this paper for changes in the consumption tax rate.

[*Blue Chip Economic Indicators*] (Experts, on Inflation rate and Real growth rate)

Conducted monthly by Wolters Kluwer. Though forecasts at a lot of horizons are available in the U.S., we use 1 indicator (1y ahead) from July 1993 for Japan. It is adjusted by the authors of this paper for changes in the consumption tax rate.

[*ESP Forecast*] (Experts, on Inflation rate and Real growth rate)

Conducted monthly by Japan Center for Economic Research. Data are from May 2004. Three indicators (1y, 2 to 6y, and 7 to 11y ahead) are available. For 2 to 6y ahead, data are from June 2009, while for 7 to 11y ahead, data are from June 2012. Respondents are asked to answer forecasts adjusted for changes in the consumption tax rate.

[*QUICK Monthly Market Survey*] (Experts, on Inflation rate)

Conducted monthly by QUICK. Data are from July 2004. Using next 1y and next 2y, we calculate 1y-1y, and using next 2y and next 10y, we calculate 2y-8y. They are adjusted by the authors of this paper for changes in the consumption tax rate.

[*Tankan*] (Firms, on Inflation rate)

Conducted quarterly by the Bank of Japan as "Short-Term Economic Survey of Enterprises in Japan." Data for "Inflation Outlook of Enterprises" are available from 2014/1Q. Three indicators (1y, 3y and 5y ahead) are used. Respondents answer choosing from 10 answers (-3% or lower, -2%, -1%, … , +5%, and +6% or higher). Here, "+5%" means "between +4.5% and +5.4%." Also, "-3% or lower" and "+6% or higher" are rounded to -3% and +6%, respectively. We use the averages of outlook which are the weighted averages by response percentages. Respondents are asked to answer forecasts adjusted for changes in the consumption tax rate.

[*QUICK Tankan*] (Firms, on Inflation rate)

Conducted monthly by QUICK as "QUICK Short-Term Economic Survey of Enterprises in Japan." Data are from January 2014. 1 indicator (1y ahead) is used. As the time series of this index is short, it isn't adjusted for changes in the consumption tax rate.

[*Opinion Survey on the General Public's Views and Behavior*] (Households, on Inflation rate)

Conducted quarterly by the Bank of Japan. We use data from 2006/2Q when the survey started to ask the same way as it is conducted currently. Using forecasts for 1y and 5y ahead, we calculate 1y-4y. In calculating average from individual data, answers above +5% and below -5% are taken away. Respondents are asked to answer forecasts adjusted for changes in the consumption tax rate.

[*Break-Even Inflation Rate* (BEI)] (Market, on Inflation rate)

Data are downloaded from Bloomberg. Calculated by subtracting yields on inflation-indexed bonds from yields on fixed-interest bonds with same maturities. Assuming that the Fisher equation is consistent, inflation expectations (BEI) is the difference between the nominal interest rate (fixed-interest bond) and the real interest rate (inflation-indexed bond). We use the indicator of which maturity is 10 years as forecast for next 10 years. Both the old BEI (since 2004) and the new BEI (since 2013) are included in the dataset. They aren't adjusted for changes in the consumption tax rate as the timing when market participants incorporate them into their forecasts is not necessarily clear.

[*Inflation Swap Rate*] (Market, on Inflation rate)

Data are downloaded from Bloomberg. Available from 2007. Obtained from the prices of financial derivatives of which the underlying asset is CPI. 5y-5y is used for analysis as derivatives at that horizon are mainly traded. It isn't adjusted for changes in the consumption tax rate as the timing when the market participants incorporate them into their forecasts is not necessarily clear.

(ii) Actual data

[Consumer price index (CPI)] (Inflation rate)

Data are released by the Ministry of Internal Affairs and Communications every month. We use the index "All items, less fresh food" which is adjusted for changes in the consumption tax rate. We use quarter-to-quarter percent change data which are seasonally adjusted by us.

[SNA (National Accounts of Japan)] (Real growth rate)
Data are released by the Cabinet Office every quarter. We use seasonally adjusted quarter-to-quarter percent change data.

[Government bond yield] (Nominal interest rate)
3-month bond rates are downloaded from Bloomberg. Interest rates on JGB from 1 to 10 years are released by the Ministry of Finance every day.

[Import Price Index (IPI)]
This index is included in the corporate goods price index (CGPI) which the Bank of Japan releases every month.

Appendix 2. Bayesian Estimation: Rule for Setting the Means of Prior Distribution of Standard Deviations of Observed Errors

As stated in Section 4, all forecasts are assumed to have observation errors. In estimation, it is important how the standard deviations of these errors are treated in a model. In a Bayesian estimation, estimated expectations could be affected by the prior distributions of the standard deviations of these errors. To eliminate arbitrariness, such as making small standard deviations of observation errors of particular survey-based forecasts, we determine the rules for setting the prior distributions as described below.

Following Crump, Eusepi, and Moench (2018), we break forecast data into three groups based on their horizons: short term (1 to 2 years ahead), medium term (3 to 4 years ahead), and long term (5 to 10 years ahead). These grouping are done for three variables, inflation rate, real growth rate and nominal interest rate, respectively. Therefore, all forecasts belong to each of the following 9 categories: inflation forecast for short-term, medium-term, and long-term; forecast of real growth rate for short-term, medium-term, and long-term; and forecast of nominal interest rate for short-term, medium-term, and long-term. It should be noted that for forecasts whose horizon extends over multiple years, they are put into the group which their average forecast year belongs (e.g. inflation swap rate for 2y-8y belongs to long term).

Next, in setting the means of prior distributions of standard deviations of observation errors, we address two "balances" among the forecast data. The first is the balance among forecast horizons. That is, we assume that the sum of the variance (or square of the standard deviation) of observation errors is the same among the 9 groups set above. This implies that more (less) information for each indicator in a group is reflected *a priori* if the group contains less (more) indicators. Further, we assume that the prior distributions of the standard deviations of observation errors are the same in each group.

The second balance is among agents: households, firms, and experts (including market participants). Counting the number of forecasts based on the types of agents (see Figure 1), the number of forecasts of experts and market participants is larger than that of forecasts of households and firms. To reflect information of forecasts of each agent equally, we multiply the number of forecasts of each agent type within a group by the mean of prior distribution of standard deviations of observation errors of that group set according to the rule above. After this modification, even within the same group, the mean of prior distribution of standard deviations of observation errors is larger for the forecasts of experts and market participants, and smaller for the forecasts of households and firms. As a result, an appropriate adjustment is made to ensure equal balance among agents *ex ante*.[29,30] Of course, the posterior distribution of standard deviations of observation errors could be different among forecasts *ex post*, because in the estimation, the observation error of a survey is estimated to be larger or smaller, depending on the model.

Appendix 3. Structure of Observation Equation: Conversion from Year-over-Year Basis, to Quarter-over-Quarter Basis

Below are details of the observation equations given in Section 4. In this appendix, the equations are based on Crump, Eusepi, and Moench (2018), as is the case with Section 4. In equation (A), we show how the inflation forecast for 1-year ahead (e.g. *Consensus Forecasts* for 1-year ahead) is connected to state variables in our model. Here, equation (A)' is the expanded version of equation (A).

$y_{t,1y}^{F1}$ in the left-hand side of equation (A)' is the value of the survey-based forecast, year-over-year-based observed variable. $y_{t+1}, \dots, y_{t+7}$ in the right-hand side are the

[29] Nishino *et al.*(2016) insist that the weights for households, firms, and experts are each one-third in their estimation of the synthesized inflation expectation indicators (SIEI). Our assumption above is consistent with their analysis.

[30] To check for robustness, we estimate the inflation expectations curves using the forecast data of experts only, excluding the forecasts of households and firms. The result is similar to the curves using the forecasts of all three types of agents.

value of inflation expectations in the model from 1-quarter to 7-quarters ahead, quarter-over-quarter-based state variables. From coefficients on these state variables, it is implied that y_{t+4}, estimated inflation expectation at 4-quarter ahead, is most reflected in the information of $y^{F1}_{t,1y}$, the observed forecast for year-over-year inflation that starts at 1-year ahead. In other words, the relationship between $y^{F1}_{t,1y}$ and y_{t+j} decays as j leaves from 4. The shape of this relationship is called "tent-shaped" in Crump, Eusepi, and Moench (2018). As the horizons at $j = 0$ and $j = 8$, the ends of the tent, represent the current year and 2-years ahead, respectively, an inflation forecast for 1-year ahead would have an effect on the inflation expectation in the model from 0 year to 2-years ahead. In addition, we multiply by 4 in the right-hand side to convert quarter-over-quarter based state variable to year-over-year based observed variable as an approximation. Finally, $\varepsilon^{F1}_{t,1y}$ is the observed error which is the residual part of the forecast not accounted for by the model expectations.

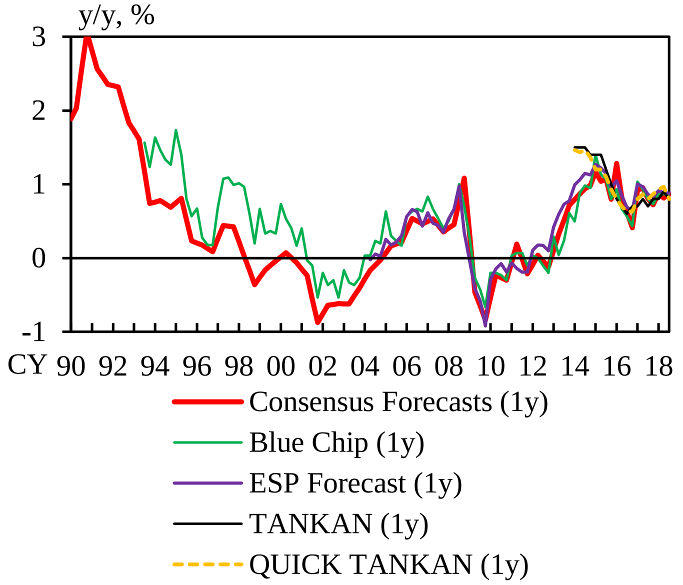
$$y^{F1}_{t,1y} = 4 \times \sum_{j=0}^{8} w_j y_{t+j} + \varepsilon^{F1}_{t,1y} \qquad \text{(A)}$$

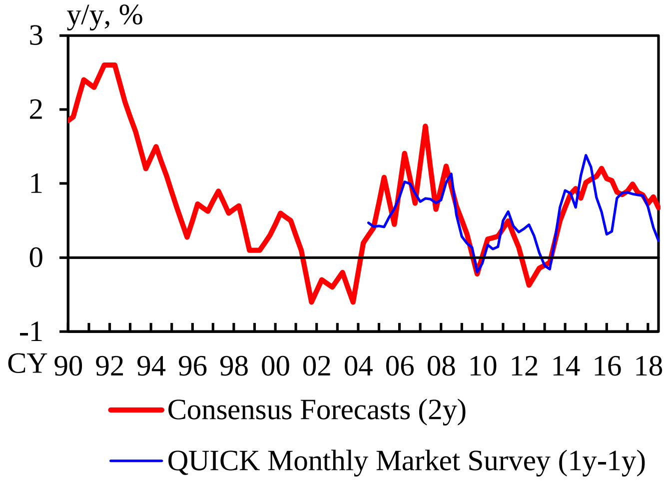
$$where\ w_j = \frac{\min(j, 8-j)}{16}$$

$$y^{F1}_{t,1y} = 4 * \frac{y_{t+1} + 2y_{t+2} + 3y_{t+3} + 4y_{t+4} + 3y_{t+5} + 2y_{t+6} + y_{t+7}}{16} + \varepsilon^{F1}_{t,1y} \qquad \text{(A)'}$$

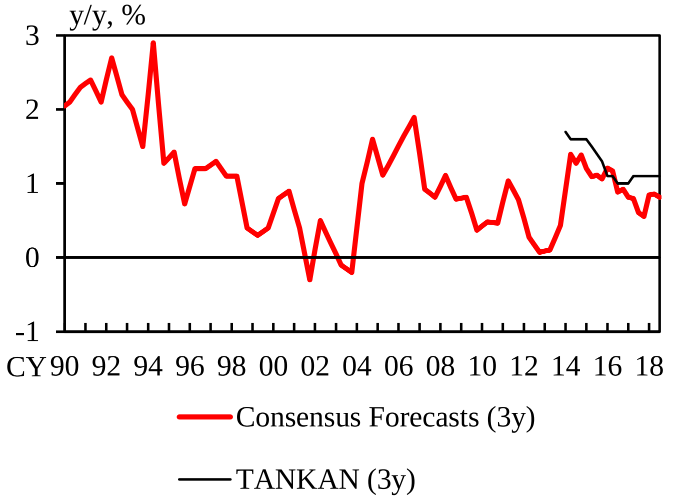
Figure 1.　Forecast Data (Inflation)

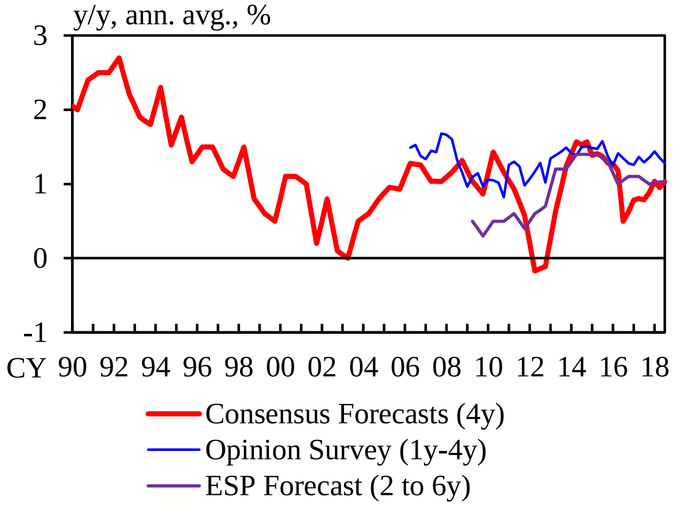
(1) Short Term (from 1 to 2 years ahead)



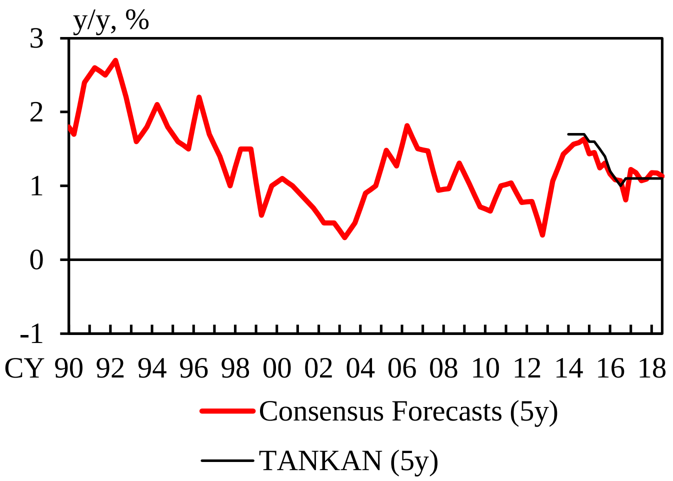


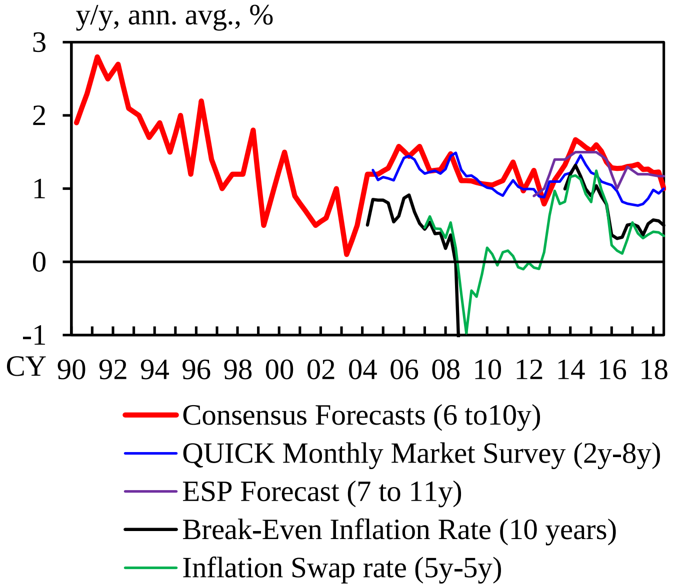
(2) Medium Term (from 3 to 4 years ahead)





(3) Long Term (from 5 to more years ahead)

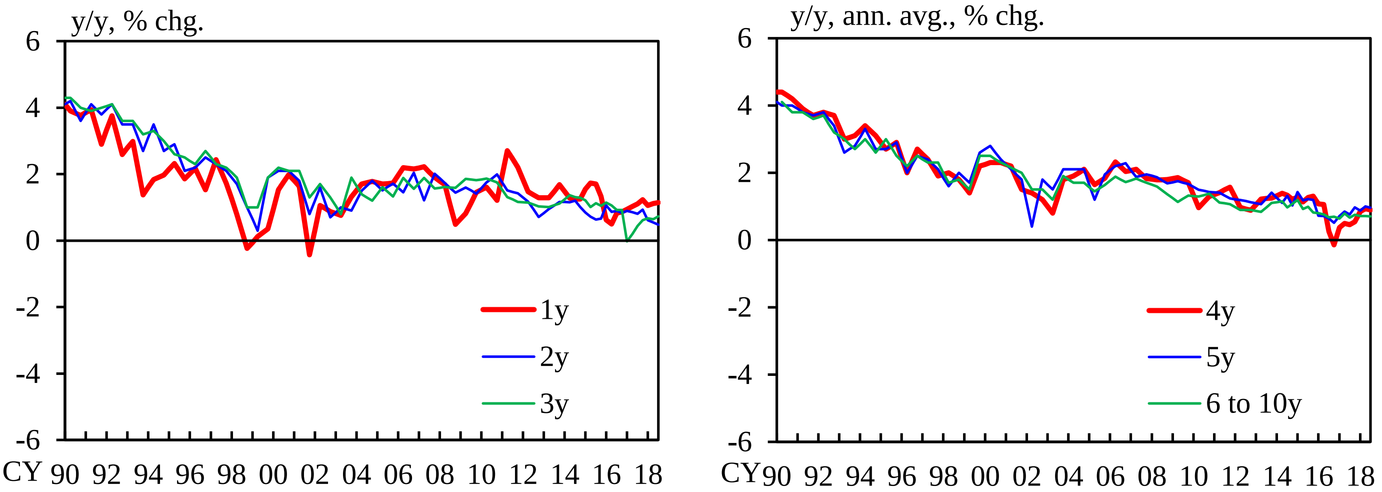




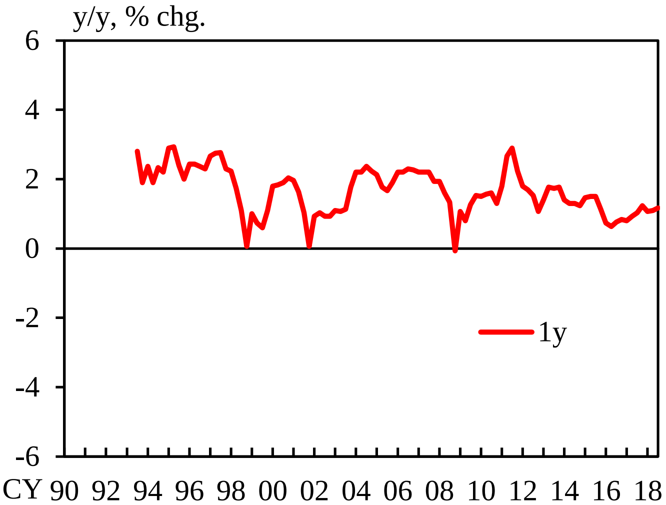
Sources: Consensus Economics "Consensus Forecasts"; QUICK; Japan Center for Economic Research; Wolters Kluwer "Blue Chip Economic Indicators"; Bank of Japan; Bloomberg, etc.

Figure 2. Forecast Data (Real Growth Rate and Nominal Interest Rate)

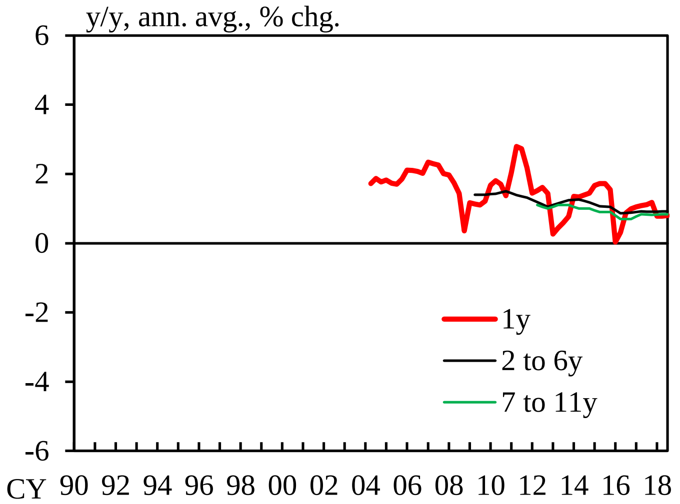
(1) Consensus Forecasts (Real Growth Rate)



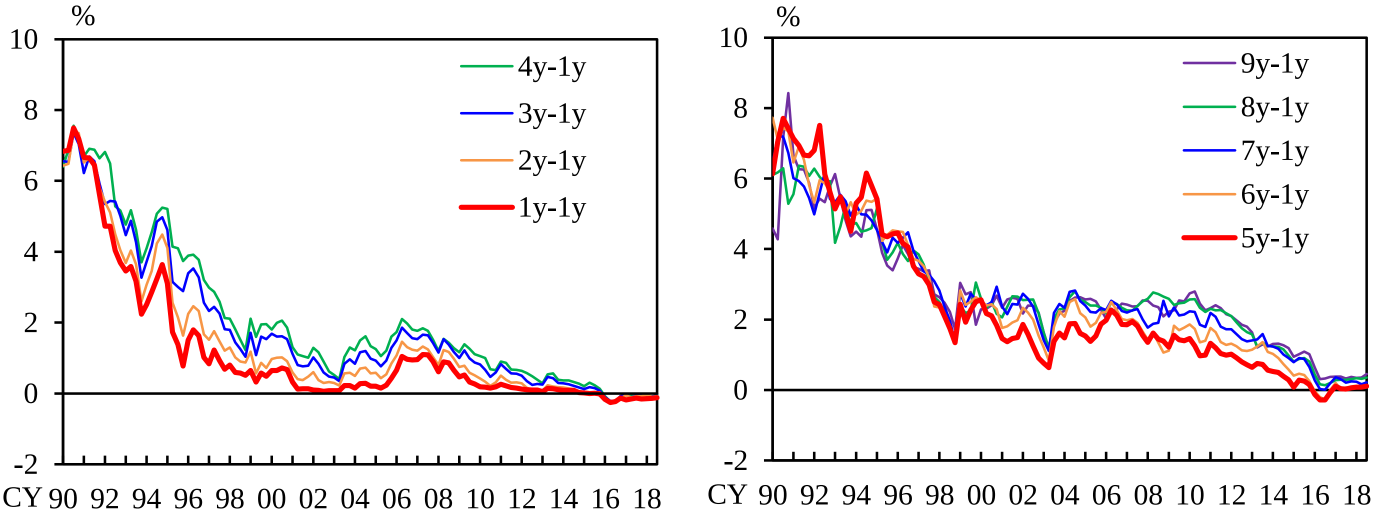
(2) Blue Chip (Real Growth Rate)



(3) ESP Forecast (Real Growth Rate)



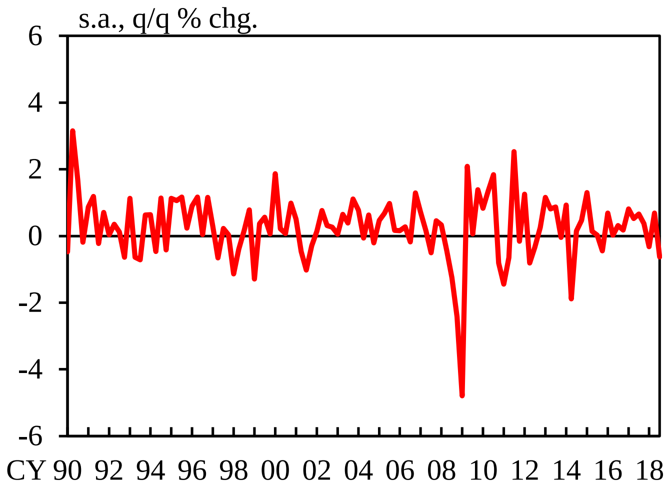
(4) Nominal Interest Rates



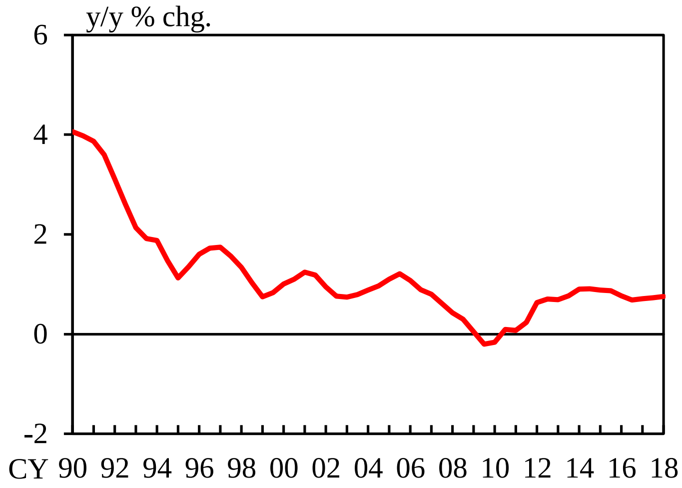
Sources: Consensus Economics "Consensus Forecasts" ; Japan Center for Economic Research;
Wolters Kluwer "Blue Chip Economic Indicators"; Ministry of Finance, etc.

Figure 3. Actual Data

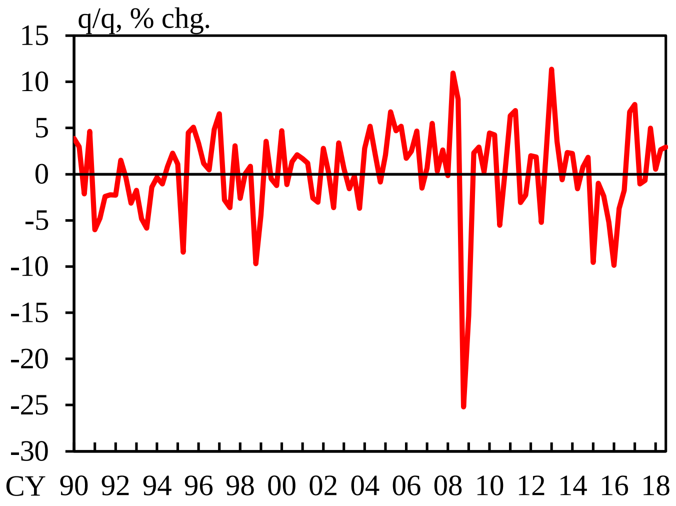
(1) Real Growth Rate



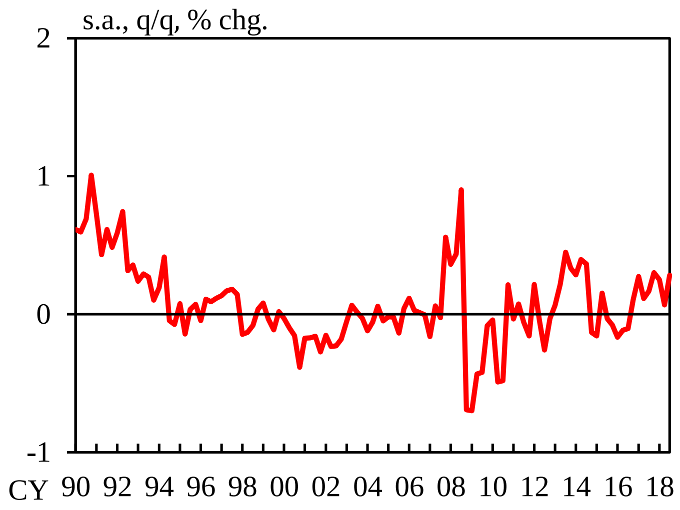
(2) Potential Growth Rate (BOJ estimation)



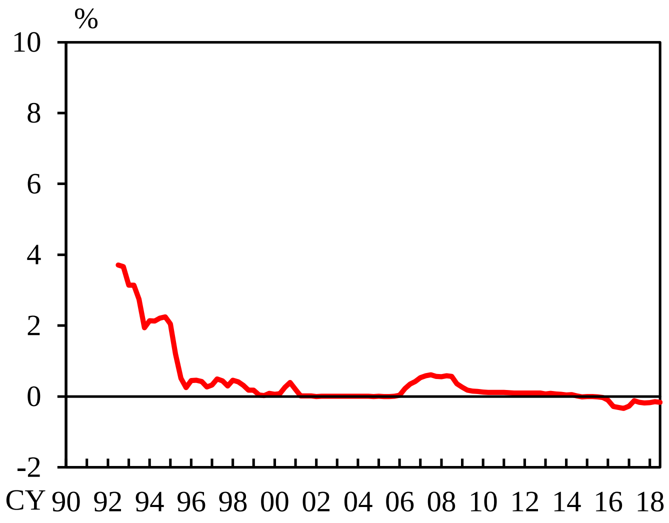
(3) Import Price Index



(4) CPI (less fresh food)



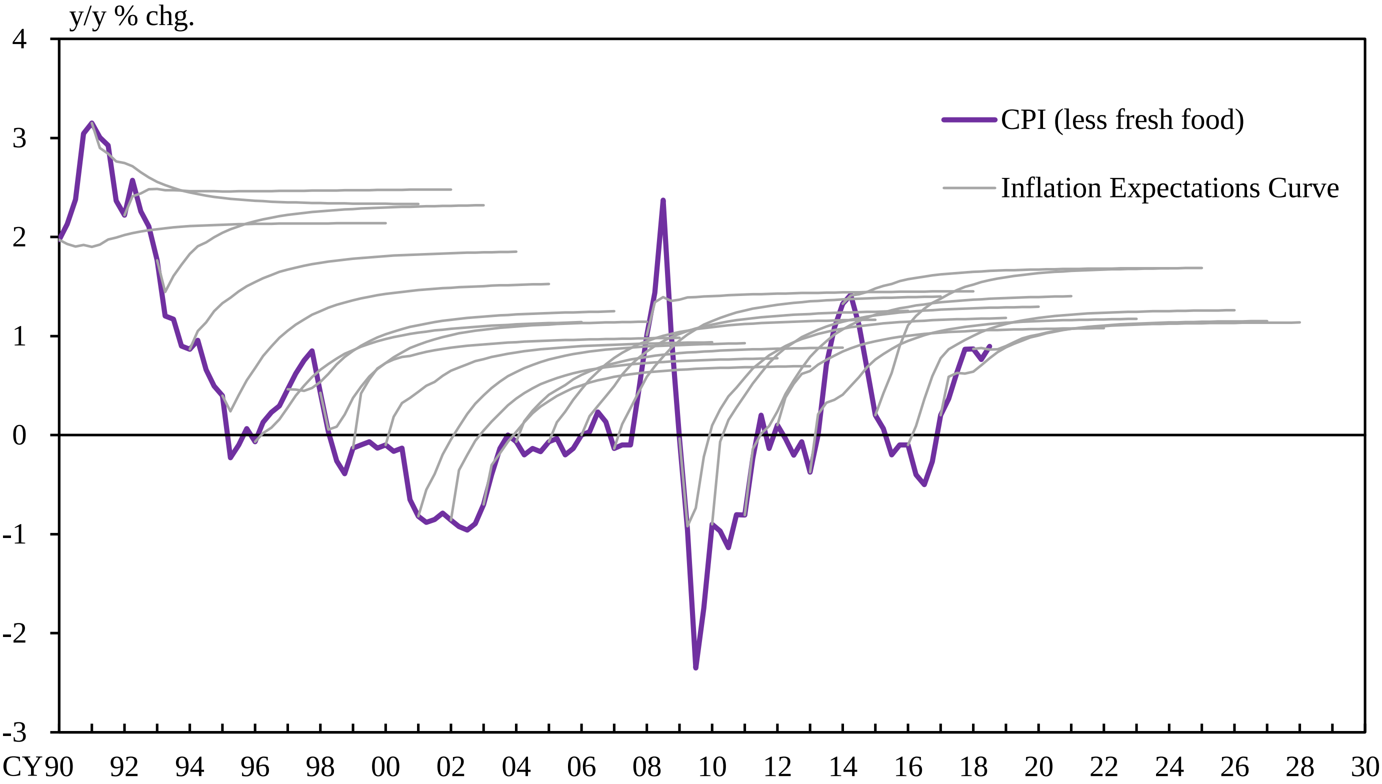
(5) Nominal Interest Rates (3-month)



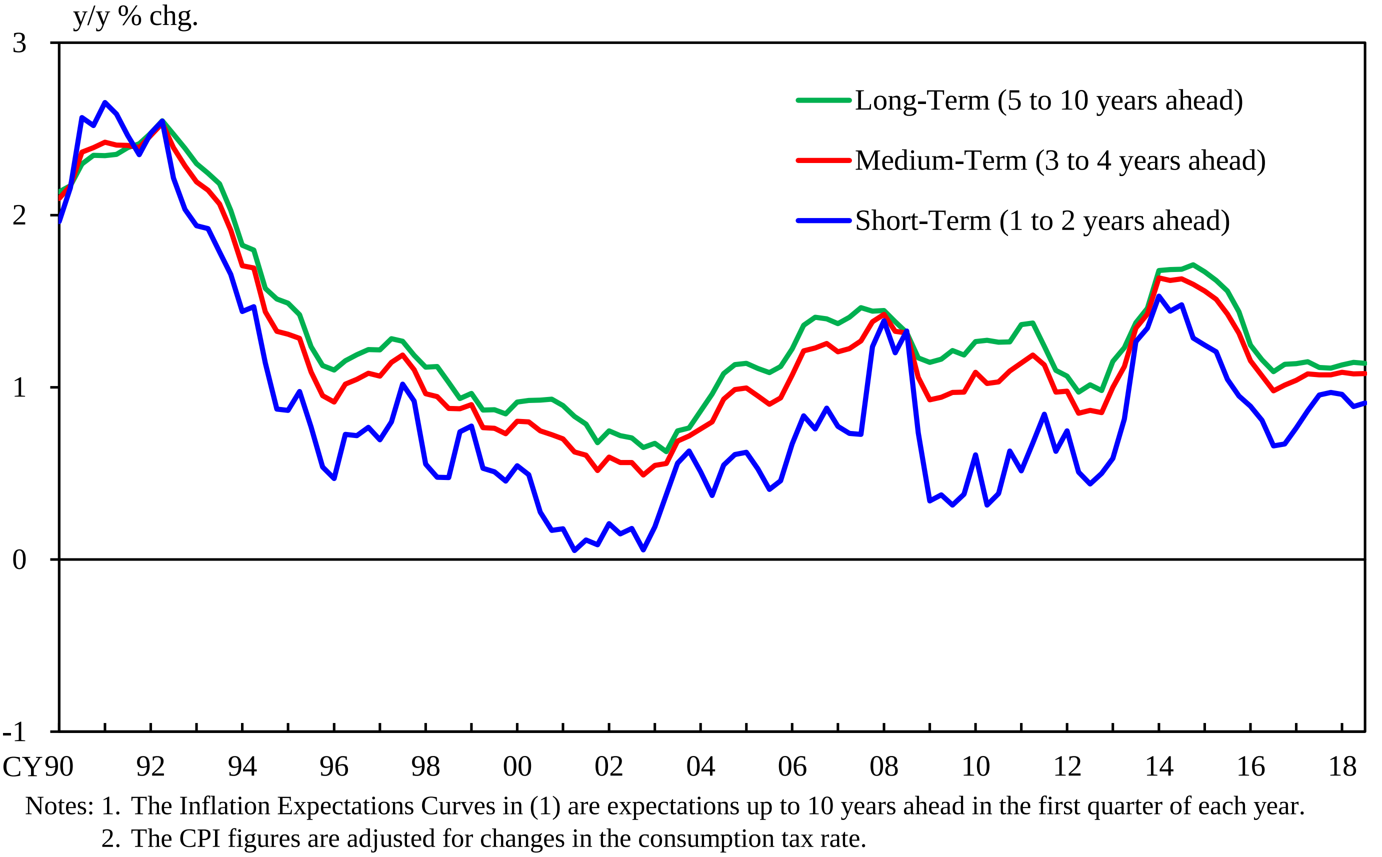
Sources: Cabinet Office; Bank of Japan; Ministry of Internal Affairs and Communications; Bloomberg.

Figure 4. Inflation Expectations Curve in Japan

(1) Inflation Expectations Curve



(2) Short-, Medium- and Long-Term Inflation Expectations

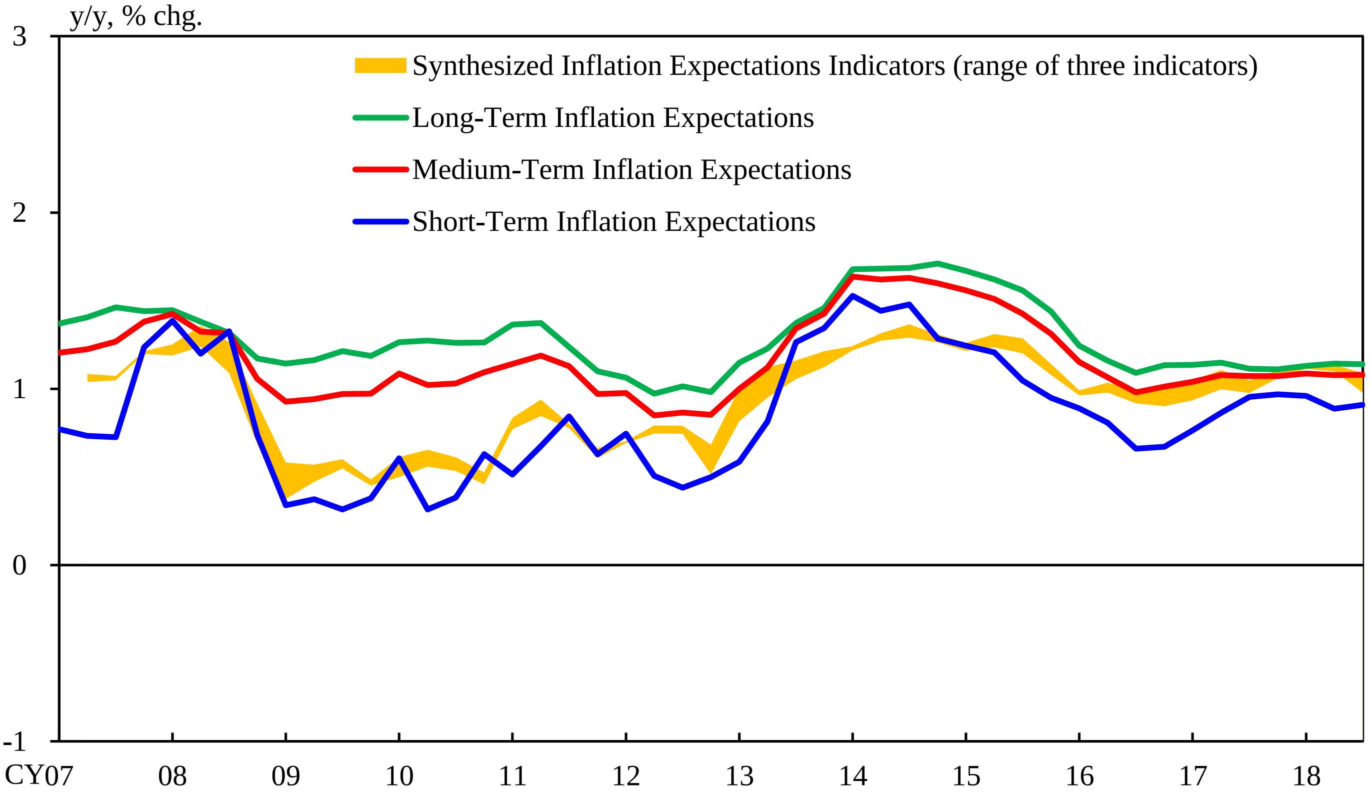


Notes: 1. The Inflation Expectations Curves in (1) are expectations up to 10 years ahead in the first quarter of each year.
2. The CPI figures are adjusted for changes in the consumption tax rate.
3. "Short-Term", "Medium-Term" and "Long-Term" in (2) are simple averages of the values for each year.

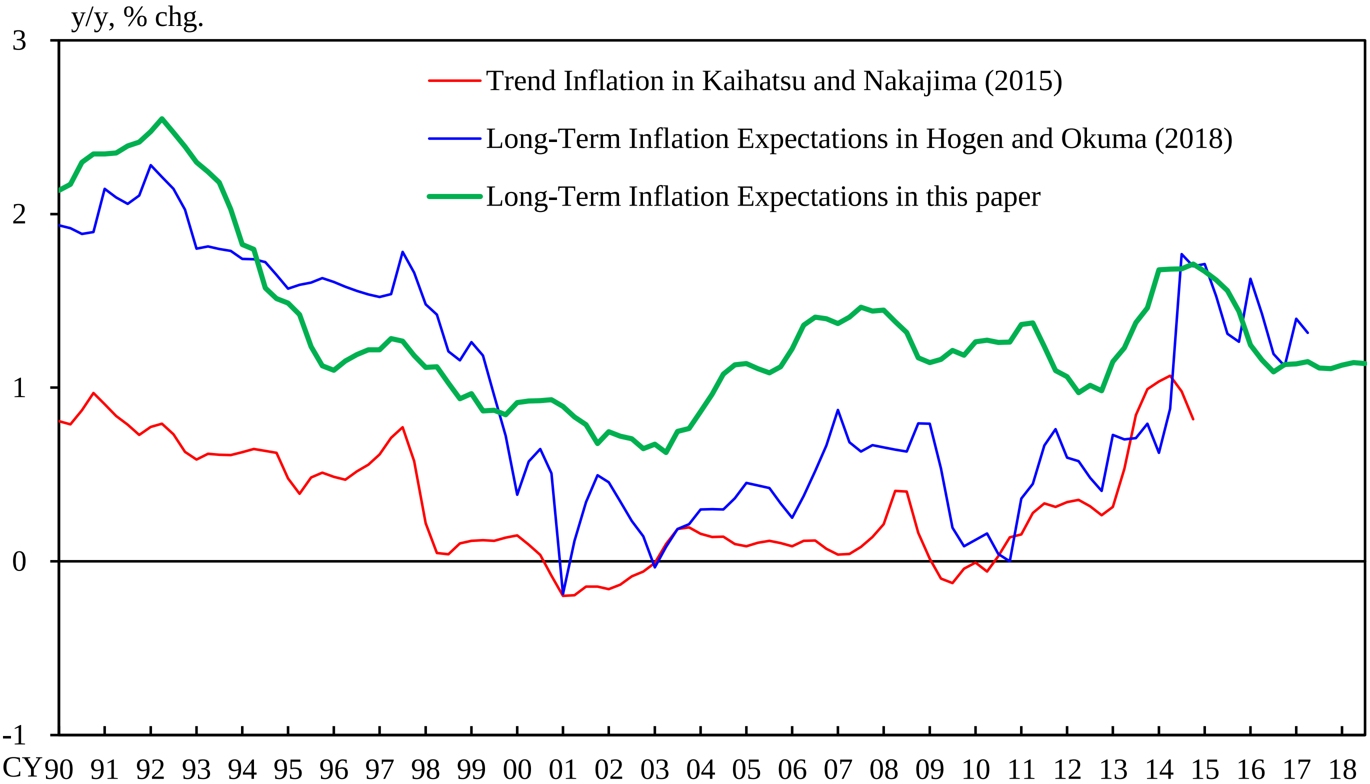
Sources: Consensus Economics "Consensus Forecasts"; QUICK; Japan Center for Economic Research; Bloomberg; Wolters Kluwer "Blue Chip Economic Indicators"; Ministry of Finance; Bank of Japan; Cabinet Office, etc.

Figure 5. Comparison with Existing Literature on Inflation Expectations

(1) Comparison with Synthesized Inflation Expectations Indicators



(2) Comparison with Kaihatsu and Nakajima (2015) and Hogen and Okuma (2018)



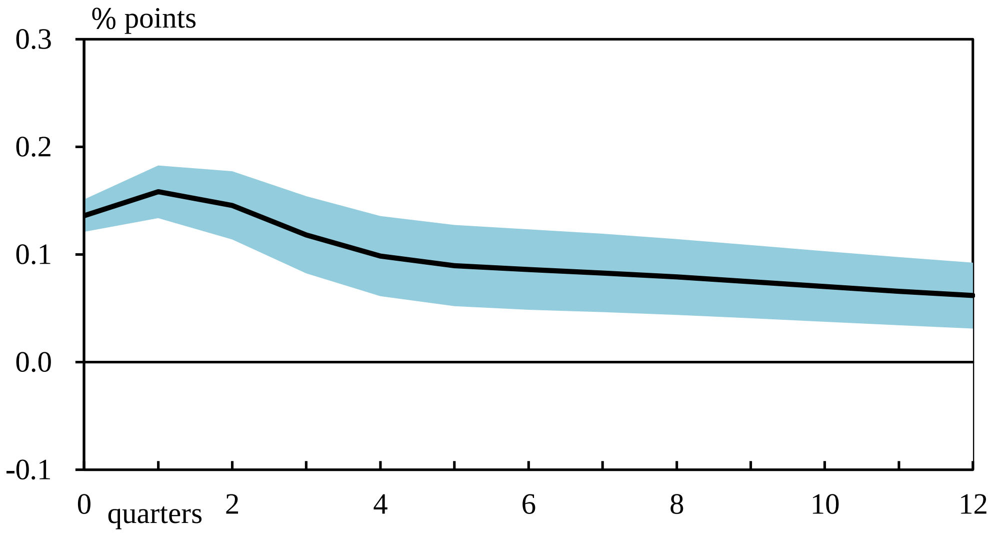
Note: The three indicators in (1) are the indicator of households', firms' and experts' inflation expectations (Consensus Forecasts), the indicator of households', firms' and experts' inflation expectations (QUICK Montly Market Survey), and the indicator of households', firms' and experts' inflation expectations (Inflation Swap Rate).

Sources: Consensus Economics "Consensus Forecasts"; QUICK; Japan Center for Economic Research; Bloomberg; Wolters Kluwer "Blue Chip Economic Indicators"; Ministry of Finance; Bank of Japan; Cabinet Office, etc.

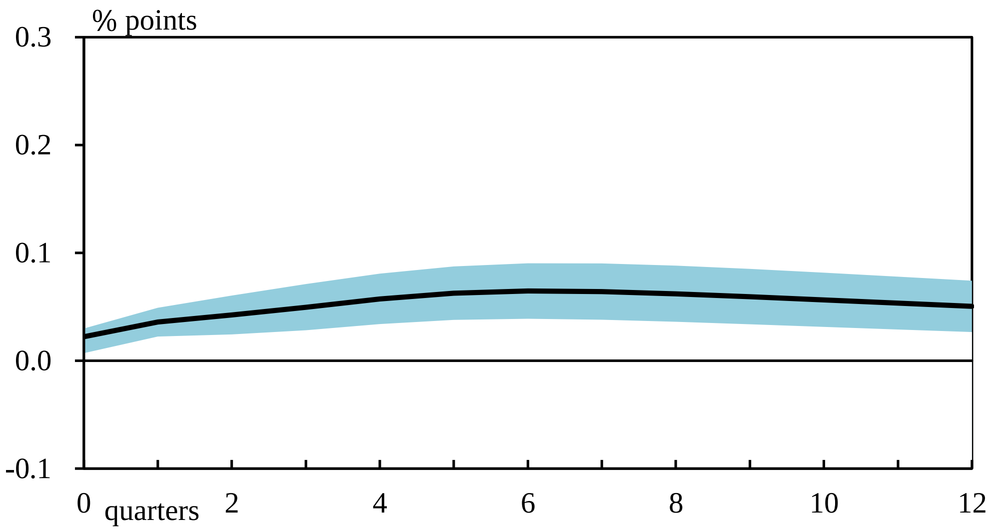
Figure 6. Impulse Response of Inflation Expectations

< Response to a 1 percentage point (annualized) shock to the actual inflation rate >

(1) Impulse Response of Short-Term Inflation Expectations



(2) Impulse Response of Long-Term Inflation Expectations



< Model Specifications>
Estimation Model: 3-variable VAR.
Shocks are identified by Cholesky decomposition in the following order:
(a) CPI all items less fresh food (q/q % chg, adjusted for changes in the consumption tax rate)
(b) Short-Term Inflation Expectations
(c) Long-Term Inflation Expectations
Estimation period: 1990/Q1-2018/Q3. Lags: 2 quarters (based on AIC criteria).
Shaded area indicates ± 1 standard error bands.

Sources: Consensus Economics "Consensus Forecasts"; QUICK; Japan Center for Economic Research; Bloomberg; Wolters Kluwer "Blue Chip Economic Indicators"; Ministry of Finance; Bank of Japan; Cabinet Office; Ministry of Internal Affairs and Communications, etc.

Table 1-1. Estimated Parameters (1)

Parameter	Distribution	Prior Distribution		Posterior Distribution		
		Mean	St.Dev.	Mean	5 percent	95 percent
CC of Real Growth Rate						
CC of Real Growth Rate (-1)	N	0.30	(0.10)	0.13	0.04	0.23
CC of Inflation Rate (-1)	N	-0.30	(0.10)	-0.28	-0.40	-0.16
CC of Nominal Interest Rate (-1)	N	0.10	(0.10)	-0.09	-0.22	0.06
Import Price Index (-1)	N	0.10	(0.10)	0.06	0.03	0.08
CC of Real Growth Rate (-2)	N	0.10	(0.10)	0.13	0.05	0.21
CC of Inflation Rate (-2)	N	0.10	(0.10)	0.09	-0.03	0.21
CC of Nominal Interest Rate (-2)	N	0.10	(0.10)	-0.05	-0.13	0.02
Import Price Index (-2)	N	0.10	(0.10)	-0.06	-0.08	-0.03
CC of Real Growth Rate (-3)	N	0.10	(0.10)	0.01	-0.06	0.07
CC of Inflation Rate (-3)	N	0.10	(0.10)	0.23	0.16	0.30
CC of Nominal Interest Rate (-3)	N	0.10	(0.10)	-0.16	-0.26	-0.05
Import Price Index (-3)	N	0.10	(0.10)	0.02	0.00	0.04
CC of Inflation Rate						
CC of Real Growth Rate (-1)	N	0.00	(0.10)	0.03	0.00	0.06
CC of Inflation Rate (-1)	N	0.04	(0.10)	0.41	0.32	0.49
CC of Nominal Interest Rate (-1)	N	0.00	(0.10)	-0.02	-0.11	0.06
Import Price Index (-1)	N	0.10	(0.10)	0.00	-0.01	0.00
CC of Real Growth Rate (-2)	N	0.10	(0.10)	0.06	0.03	0.08
CC of Inflation Rate (-2)	N	0.10	(0.10)	0.03	-0.04	0.11
CC of Nominal Interest Rate (-2)	N	0.10	(0.10)	0.03	-0.05	0.12
Import Price Index (-2)	N	0.10	(0.10)	0.00	-0.01	0.00
CC of Real Growth Rate (-3)	N	0.10	(0.10)	-0.03	-0.05	-0.01
CC of Inflation Rate (-3)	N	0.10	(0.10)	0.26	0.19	0.34
CC of Nominal Interest Rate (-3)	N	0.10	(0.10)	0.02	-0.07	0.11
Import Price Index (-3)	N	0.10	(0.10)	-0.01	-0.01	0.00
CC shock of Real Growth Rate	N	0.10	(0.10)	0.02	-0.02	0.05
CC of Nominal Interest Rate						
CC of Real Growth Rate (-1)	N	0.10	(0.10)	0.00	-0.01	0.01
CC of Inflation Rate (-1)	N	-0.30	(0.10)	-0.05	-0.10	-0.01
CC of Nominal Interest Rate (-1)	N	1.00	(0.10)	1.04	0.97	1.10
Import Price Index (-1)	N	0.10	(0.10)	0.00	0.00	0.00
CC of Real Growth Rate (-2)	N	0.10	(0.10)	0.00	-0.01	0.01
CC of Inflation Rate (-2)	N	0.10	(0.10)	0.02	-0.03	0.07
CC of Nominal Interest Rate (-2)	N	0.10	(0.10)	-0.05	-0.14	0.04
Import Price Index (-2)	N	0.10	(0.10)	0.00	0.00	0.00
CC of Real Growth Rate (-3)	N	0.10	(0.10)	0.01	0.00	0.01
CC of Inflation Rate (-3)	N	0.10	(0.10)	0.09	0.06	0.13
CC of Nominal Interest Rate (-3)	N	0.10	(0.10)	-0.03	-0.10	0.04
Import Price Index (-3)	N	0.10	(0.10)	0.00	0.00	0.00
CC shock of Inflation Rate	N	0.10	(0.10)	0.12	0.06	0.18
CC shock of Real Growth Rate	N	0.10	(0.10)	0.02	0.01	0.04
Import Price Index						
Import Price Index (-1)	N	0.70	(0.10)	0.42	0.34	0.51
Import Price Index (-2)	N	0.10	(0.10)	-0.13	-0.22	-0.05
Fisher Equation						
TC of Real Growth Rate	G	1.00	(0.10)	0.71	0.62	0.81

Notes: 1. N stands for normal distribution, G for gamma distribution, invG for inverse gamma distribution.
2. Mean of prior distribution of parameters of variable(-1), Fisher equation and SD of shocks is based on Crump, Eusepi, and Moench (2018).
3. CC stands for Cyclical Component, TC for Trend Component.

Table 1-2. Estimated Parameters (2)

Parameter	Distribution	Prior Distribution		Posterior Distribution		
		Mean	St.Dev.	Mean	5 percent	95 percent
SD of Shocks						
CC of Real Growth Rate	invG	0.70	(0.10)	0.89	0.81	0.97
CC of Inflation Rate	invG	0.01	(0.10)	0.21	0.18	0.23
CC of Nominal Interest Rate	invG	0.20	(0.10)	0.08	0.07	0.10
Import Price Index	invG	5.00	(0.10)	4.96	4.83	5.07
TC of Real Growth Rate	invG	0.10	(0.10)	0.10	0.09	0.11
TC of Inflation Rate	invG	0.10	(0.10)	0.04	0.03	0.04
TC of Nominal Interest Rate	invG	0.30	(0.10)	0.12	0.11	0.14
SD of Measurement Errors						
Inflation Rate						
Consensus Forecasts (1y)	invG	1.00	(0.10)	0.72	0.65	0.80
Consensus Forecasts (2y)	invG	1.00	(0.10)	0.74	0.66	0.82
Consensus Forecasts (3y)	invG	0.60	(0.10)	0.47	0.41	0.53
Consensus Forecasts (4y)	invG	0.60	(0.10)	0.42	0.36	0.47
Consensus Forecasts (5y)	invG	1.20	(0.10)	0.88	0.80	0.95
Consensus Forecasts (6 to 10y)	invG	1.20	(0.10)	0.90	0.82	0.98
ESP Forecast (1y)	invG	1.00	(0.10)	0.74	0.67	0.83
ESP Forecast (2 to 6y)	invG	0.60	(0.10)	0.47	0.38	0.56
ESP Forecast (7 to 11y)	invG	1.20	(0.10)	1.10	1.01	1.20
Blue Chip (1y)	invG	1.00	(0.10)	0.68	0.61	0.73
QUICK Monthly Market Survey (1y-1y)	invG	1.00	(0.10)	0.72	0.66	0.78
QUICK Monthly Market Survey (2y-8y)	invG	1.20	(0.10)	0.92	0.82	1.01
Break-Even Inflation Rate (10 years)	invG	1.20	(0.10)	1.13	1.00	1.26
Inflation Swap Rate (5y-5y)	invG	1.20	(0.10)	1.08	1.00	1.17
Opinion Survey (1y-4y)	invG	0.20	(0.10)	0.37	0.28	0.44
Tankan (1y)	invG	0.40	(0.10)	0.26	0.21	0.32
Tankan (3y)	invG	0.20	(0.10)	0.09	0.07	0.12
Tankan (5y)	invG	0.20	(0.10)	0.09	0.07	0.11
QUICK Tankan (1y)	invG	0.40	(0.10)	0.24	0.19	0.29
Real Growth Rate						
Consensus Forecasts (1y)	invG	0.30	(0.10)	0.75	0.67	0.82
Consensus Forecasts (2y)	invG	0.30	(0.10)	0.56	0.49	0.63
Consensus Forecasts (3y)	invG	0.30	(0.10)	0.48	0.42	0.54
Consensus Forecasts (4y)	invG	0.30	(0.10)	0.47	0.41	0.53
Consensus Forecasts (5y)	invG	0.30	(0.10)	0.49	0.43	0.56
Consensus Forecasts (6 to 10y)	invG	0.30	(0.10)	0.48	0.41	0.54
ESP Forecast (1y)	invG	0.30	(0.10)	0.63	0.55	0.71
ESP Forecast (2 to 6y)	invG	0.30	(0.10)	0.34	0.27	0.41
ESP Forecast (7 to 11y)	invG	0.30	(0.10)	0.21	0.15	0.26
Blue Chip (1y)	invG	0.30	(0.10)	0.73	0.65	0.80
Nominal Interest Rate (Forward Rate)						
1y-1y	invG	0.40	(0.10)	0.23	0.20	0.25
2y-1y	invG	0.40	(0.10)	0.24	0.21	0.26
3y-1y	invG	0.40	(0.10)	0.23	0.20	0.26
4y-1y	invG	0.40	(0.10)	0.28	0.24	0.32
5y-1y	invG	0.20	(0.10)	0.34	0.30	0.39
6y-1y	invG	0.20	(0.10)	0.31	0.27	0.35
7y-1y	invG	0.20	(0.10)	0.38	0.34	0.43
8y-1y	invG	0.20	(0.10)	0.53	0.46	0.59
9y-1y	invG	0.20	(0.10)	0.62	0.56	0.69