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The Formation of Firms' Inflation Expectations: A Survey Data Analysis[*]

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Abstract

In this paper, using both semi-aggregate and firm-level survey data of the inflation expectations of Japanese firms, we examine the empirical validity of three hypotheses on the formation of inflation expectations: the full-information rational expectations (FIRE), noisy information, and sticky information hypotheses. Our main findings are as follows. First, the results of our panel VAR analysis using semi-aggregate data show that, while firms' inflation expectations have a forward-looking aspect consistent with FIRE, they are not fully consistent with FIRE in that they tend to incorporate the changes in the actual inflation rate only gradually. Second, the forecast errors of semi-aggregate inflation expectations correlate with the past revisions of expectations, implying that FIRE does not hold for all firms. Third, the results of firm-level dynamic panel regressions show that firms' inflation expectations depend to a great extent on their past expectations, which is consistent with both the noisy information and sticky information hypotheses. The regression results also show that the short-term expectations of small firms are influenced by their perception of their own business conditions, which is consistent with the noisy information hypothesis, especially the rational inattention variant. These findings suggest that firms in Japan form their inflation expectations in a complex manner that cannot be described by a single theory.

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Keywords: Firms' inflation expectations; Survey data; FIRE; Noisy information; Sticky information

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1 Introduction

In modern macroeconomics, firms' inflation expectations are one of the key determinants of inflation rates. In theory, as long as firms have certain market power and incur some costs (of any form) in changing their prices, as assumed in the New Keynesian Phillips curve, changes in firms' inflation expectations have a crucial effect on inflation dynamics, because firms *are* the price-setters.

Current textbook macroeconomic models usually assume *full-information rational expectations* (FIRE) for the formation of firms' inflation expectations. However, there has been skepticism over the empirical plausibility of FIRE, and recent empirical studies using micro data point out its limited explanatory power (Coibion et al. 2018a).

As an alternative to FIRE, two hypotheses based on imperfect information have been attracting particular attention in the recent literature.[1] One of them is the *noisy information hypothesis*, under which economic agents need to remove noise from the information available, including the perception they have of their own business, and thus update their expectations only gradually (Phelps 1970, Lucas 1972).[2] The other is the *sticky information hypothesis*, which assumes that economic agents do not necessarily update their expectations every period due to the costs associated with acquiring new information (Mankiw and Reis 2002, Reis 2006).

A number of empirical studies have examined the empirical validity of these hypotheses using survey data of households' or professional forecasters' inflation expectations. However, there are relatively few empirical studies using survey data of firms' inflation expectations. One reason is that, until recently, only a limited number of surveys on inflation expectations had been conducted covering a wide range of firms.

In this paper, we use survey inflation expectations of Japanese firms to examine the empirical validity of the three hypotheses mentioned above: the FIRE, noisy information

[1] There are also other hypotheses on expectations formation, e.g., the *bounded rationality hypothesis* (Sargent 1993, Gabaix 2014) and the *adaptive learning hypothesis* (Evans and Honkapohja 1999, 2001). Under these hypotheses, while agents have full information about macroeconomic variables, they have only imperfect information about the structure of the economy, and as a result their formation of inflation expectations deviates from FIRE. For more details of the various hypotheses on inflation expectations, including those mentioned above, see the comprehensive survey by Coibion et al. (2018a).

[2] There are several variations and extensions of the noisy information hypothesis, such as the *rational inattention hypothesis* (proposed by Sims 2003 and Maćkowiak and Wiederholt 2009) and the *higher-order belief hypothesis* (proposed by Woodford 2003).

and sticky information hypotheses. The survey on inflation expectations has been conducted since 2014 as part of the *Short-Term Economic Survey of Enterprises in Japan* (*Tankan*), which is carried out by the Bank of Japan and covers nearly 10,000 Japanese firms. We use both semi-aggregate and firm-level data of the survey to examine the hypotheses.

Our main findings are as follows. First, the results of our panel VAR analysis using semi-aggregate data show that, while shocks to firms' long-term expectations propagate to their short-term expectations consistently with FIRE, firms' inflation expectations are not fully consistent with FIRE in that they tend to incorporate the changes in the actual inflation rate only gradually. Second, the forecast errors of semi-aggregate inflation expectations correlate with the past revisions of expectations, implying a rejection of the null hypothesis that FIRE holds for all firms. Third, the results of firm-level dynamic panel regressions show that firms' inflation expectations depend to a great extent on their past expectations, which is consistent with both the noisy information and sticky information hypotheses. The regression results also show that the short-term expectations of small firms are influenced by their perception of their own business conditions, which is consistent with the noisy information hypothesis, especially the rational inattention variant. These findings suggest that firms in Japan form their inflation expectations in a complex manner that cannot be described by a single theory.

Our results are consistent with those reported by a gradually increasing number of empirical studies on the formation of firms' inflation expectations using survey data. For instance, one of the papers by Coibion and Gorodnichenko (2015), who are leading the research in this area, examines the correlation between forecast errors and past revisions in aggregate inflation expectations of various economic agents in the U.S., and reports that FIRE is disconfirmed by the data, while both the noisy information and sticky information hypotheses are supported. Adopting similar empirical approaches, Boneva et al. (2016) and Richards and Verstraete (2016) report disconfirmation of FIRE for the survey inflation expectations of U.K. manufacturing firms and Canadian firms respectively. Also, several empirical studies report that firms' inflation expectations are affected by their own business conditions, as the noisy information hypothesis suggests. Coibion et al. (2018b) and Kumar et al. (2015) examine firm-level data obtained from surveys that they conducted with New Zealand firms, and point out that firms' inflation expectations are affected by price developments and competition in their own industries, as well as by the actual inflation rate. Furthermore, the study of Richards and Verstraete (2016) mentioned above also reports that firms' inflation expectations are influenced by firm-specific factors, such as their perception of labor shortages and their outlook for wages and input prices, as well as macroeconomic conditions such as oil prices.

In Japan, the number of empirical studies on firms' inflation expectations has been increasing. In particular, since the survey on inflation expectations was launched as a part of the *Tankan* in 2014, several empirical studies have examined the large panel data of around 10,000 firms. Uno et al. (2018) analyze the frequency of revisions of inflation expectations using the *Tankan* data, and report that the formation of firms' inflation expectations is consistent with the sticky information hypothesis. Inamura et al. (2017) and Economic Analysis Group of the Bank of Japan (2017) apply machine learning techniques to the *Tankan* data, and report that the firms' inflation expectations are affected by firm-specific information such as their own input prices, as well as by macroeconomic information such as oil prices. Besides the studies using the *Tankan* data, Kaihatsu and Shiraki (2016) use firm-level data of the *Annual Survey of Corporate Behavior* (conducted by the Economic and Social Research Institute of the Cabinet Office) to analyze publicly-listed firms' inflation expectations (in terms of the GDP deflator), and report that inflation expectations for shorter horizons tend to be affected by their own outlook for input prices and foreign exchange rates.

Compared with these previous studies, the main feature of this paper is its use of both semi-aggregate and firm-level data to examine the formation of firms' inflation expectations from several different perspectives. Another feature is its explicit inclusion of the noisy information hypothesis in the scope of hypotheses to be examined in the empirical analysis. One of its main contributions to the literature is to offer empirical evidence supporting the noisy information hypothesis as well as the sticky information hypothesis from the results of firm-level panel data analysis.

The rest of the paper is organized as follows. Section 2 describes the *Tankan* data we use in this paper. Section 3 examines the empirical validity of FIRE, using semi-aggregate data. Section 4 examines the empirical validity of the noisy information and sticky information hypotheses by conducting a dynamic panel regression analysis on firm-level data. Section 5 concludes.

2 Data

In this paper, we use the data of inflation expectations ("outlook for general prices") and judgment survey items of the *Tankan*. This section describes these data.

The *Tankan* is a statistical survey of private enterprises in Japan that is conducted by the Bank of Japan on a quarterly basis (March, June, September, and December for each year). The population of the survey is private enterprises in Japan (excluding financial institutions) with capital of 20 million yen or more, according to the *Economic Census* conducted by the Ministry of Internal Affairs and Communications and the Ministry of Economy, Trade and Industry.[3] Sample enterprises are selected for each stratum of the population divided by industry and size. As of March 2019, the total number of the sample enterprises is 9,830 (1,922 large enterprises, 2,751 medium-sized enterprises and 5,157 small enterprises).[4]

The survey of "outlook for general prices" has been conducted as a part of the *Tankan* since March 2014. Figure 1 shows the questionnaire for this survey. It asks the firms to give their outlook on 1-year-, 3-year- and 5-year-ahead inflation in terms of annual percent change in Consumer Price Index (CPI). The firms answer by choosing one of the numeric options of ten integer values ranging from –3% to +6%.[5] In this paper, we use the data of the firms' answers to this survey as their inflation expectations and examine their formation mechanism.[6]

[3] In addition to financial institutions, some industries that may have only a weak link to economic conditions, such as "education, learning support" and "medical health care and welfare," are also excluded from the population of the *Tankan*.

[4] The classification of enterprise size is defined as follows. (1) Large enterprises are those with capital of 1 billion yen or more; (2) medium-sized enterprises are those with capital from 100 million yen to less than 1 billion yen; (3) small enterprises are those with capital from 20 million yen to less than 100 million yen.

[5] Other than the numeric options, there is also an option for "no clear views on general prices." In the March 2019 round of the survey, the shares of firms that chose numeric options for the 1-year-ahead outlook were 76% for large enterprises, 87% for medium-sized enterprises, and 89% for small enterprises. Those for the 5-year-ahead outlook were 44% for large enterprises, 59% for medium-sized enterprises, and 64% for small enterprises.

[6] The *Tankan* also has a survey of "outlook for output prices," but we do not use the data of this survey because we focus on the firms' expectations on general-price inflation in this paper.

From the sample for the analyses in this paper, however, we exclude the data for the first one year of the survey. This is because investigating the firm-level data of the survey reveals that the firms' answers during the early period of the survey were unstable in the following ways. First, as Panel (1) of Figure 2 shows, the ratio of firms with large forecast revisions (more than 2% points upward or downward) was high for a while from the beginning of the survey. Second, as can be seen in Panel (2) of Figure 2, which shows the ratio of firms that changed their inflation expectations in the opposite direction to that which they had given in the previous round of the survey, an irregular "zigzag" pattern of revisions was fairly common for a while after the beginning of the survey. In order to prevent such unstable answers from influencing the empirical results as far as possible, we exclude the data for the first year of the survey from the sample for the analyses. Namely, we set our sample to the period from 2015Q1 to 2019Q1.[7]

When we conduct a dynamic panel regression analysis in section 4, we also use the data of firms' answers to judgment items, in addition to the data on inflation expectations. Judgment items ask for firms' qualitative assessments of the "current" and "forecasted" (for the next survey period) conditions of their business.[8] For example, the item for the "current" judgment on "change in input prices" asks for the change in their own input prices from three months earlier, and firms choose one of the three options: "rise," "unchanged," and "fall." In the dynamic panel regression analysis in section 4, we use as explanatory variables the firms' answers for "current" judgments on "change in input prices," "change in output prices," "domestic supply and demand conditions," "employment conditions" and so on, to examine the relationship between the firms' inflation expectations and their assessment of their own business conditions.

3 Examination of the Empirical Validity of FIRE

In this section, we examine the empirical validity of FIRE using semi-aggregate data of firms' inflation expectations. We first estimate a panel VAR model to check the impulse responses of firms' inflation expectations to shocks to long-term expectations and the

[7] We checked, however, that the main results in this paper do not change significantly if we include the data for the first one year of "outlook for general prices" in our sample.

[8] "Forecasted" judgments are not surveyed for all items.

actual inflation rate and discuss the consistency between the results and FIRE. We then examine whether FIRE alone can explain the formation of firms' inflation expectations with a statistical test on the forecast errors of firms' inflation expectations.

3.1 Examination Using Panel VAR

If firms formed their inflation expectations in accordance with FIRE, they would make full use of available information about the economy to forecast inflation rates. In this case, firms would form their inflation expectations in a forward-looking manner, taking into account, in particular, the long-term outlook for inflation rates. Hence, if inflation expectations at longer horizons rose due to a change in the longer-term outlook for inflation rates, this would also affect short-term inflation expectations.

In addition, under FIRE, firms on average would accurately forecast future inflation rates. Therefore, if the actual inflation rate changed unexpectedly, they would immediately revise their inflation expectations to correctly incorporate the subsequent dynamics of inflation rates.

To check whether these characteristics can be observed in the data of firms' inflation expectations, we estimate a panel VAR model using semi-aggregate data of firm groups by industry and size, and then calculate the impulse responses. The model includes 1-year- and 5-year-ahead inflation expectations as endogenous variables and the actual inflation rate as an exogenous variable.[9] Specifically, we estimate the following model:

$$\begin{bmatrix} \pi^{e,k}_{t+4|t} \\ \pi^{e,k}_{t+20|t} \end{bmatrix} = \sum_{j=1}^{p} A_{k,j} \begin{bmatrix} \pi^{e,k}_{t-j+4|t-j} \\ \pi^{e,k}_{t-j+20|t-j} \end{bmatrix} + \sum_{j=1}^{p} B_{k,j} \widetilde{\pi}_{t-j} + \begin{bmatrix} \varepsilon^{1Y}_{k,t} \\ \varepsilon^{5Y}_{k,t} \end{bmatrix}, \tag{1}$$

where $\pi^{e,k}_{t+4|t}$ and $\pi^{e,k}_{t+20|t}$ are 1-year-ahead (i.e. 4-quarter-ahead) and 5-year-ahead (i.e. 20-quarter-ahead) average inflation expectations of firm group k at period t. $\widetilde{\pi}_t$ is the actual inflation rate (CPI, all items less fresh food, seasonally adjusted, annualized quarter-on-quarter percent changes).[10,11] $A_{k,j}$ and $B_{k,j}$ are coefficient matrices.

[9] We treat inflation rates as exogenous variables because the semi-aggregate inflation expectations of each of the firm groups, which are finely partitioned by firm size and industry, should not have a large influence on aggregate-level inflation rates.

[10] The average inflation expectations of each group are calculated using only the data for firms within the group that answered numeric values for both 1-year- and 5-year-ahead expectations.

[11] Since the main focus here is to examine the response of inflation expectations to shocks to the

In the estimation, we use the panel data of inflation expectations of 93 firm groups, which are stratified based on the 3 firm sizes (large, medium-sized, and small) and the 31 industry classifications used in the *Tankan*. The ordering of the Cholesky decomposition for VAR is such that 5-year-ahead expectations are placed before 1-year-ahead expectations.[12] The order of lag, p, is set to 2, based on the information criteria proposed by Andrews and Lu (2001). The sample period is from 2015Q1 to 2019Q1.

Figure 3 shows the impulse responses to a +1% point shock in 5-year-ahead inflation expectations, whereas Figure 4 shows the impulse responses to a +1% point shock in the actual inflation rate.[13]

The result of Figure 3 indicates that there is a statistically significant rise in 1-year-ahead inflation expectations following the rise in 5-year-ahead inflation expectations. This result implies that the formation of firms' inflation expectations has a forward-looking aspect in the sense that firms take into account the long-term outlook for inflation rates in forming their short-term inflation expectations. This is consistent with FIRE.

On the other hand, firms' inflation expectations have a feature that is not consistent with FIRE. The impulse responses of inflation expectations to a positive shock to the actual inflation rate shown in Figure 4 indicate that, while the actual inflation rate monotonically declines after its immediate rise on impact, 1-year- and 5-year-ahead expectations only gradually increase and reach their peak with lags of one year or more. As such, the formation of firms' inflation expectations has a tendency to incorporate the changes in the actual inflation rate only gradually.[14] If the formation of firms' inflation expectations were fully consistent with FIRE, firms would on average accurately forecast

underlying factors of inflation (not transient factors), we use "CPI (all items less fresh food)" in calculating the inflation rate. The impulse responses do not change significantly if we use "CPI (all items)" instead.

[12]The results do not change qualitatively if we change the ordering of the Cholesky decomposition, or if we employ the method of generalized impulse responses.

[13]Impulse responses to the shock in the actual inflation rate are calculated as follows. First, we estimate an AR(2) model for the actual inflation rate to capture its dynamics using the data from 1990Q1 to 2019Q1. Next, we calculate the impulse responses of the actual inflation rate by putting a +1% point shock into the AR(2) model. Then we plug them into the terms of the actual inflation rate in equation (1) to calculate the impulse responses of inflation expectations.

[14]Several works have shown that inflation expectations in Japan tend to only gradually incorporate the changes in the actual inflation rate. For example, Bank of Japan (2018) points out such a tendency for professional inflation forecasts, and Maruyama and Suganuma (2019) report similar results using a compound index of inflation expectations constructed using various survey and market data. Based on these results, they argue that inflation expectations in Japan are strongly affected by the adaptive formation mechanism.

the actual inflation rate, and thus their inflation expectations would immediately rise on impact and decline monotonically afterwards, as the actual inflation rate does. Hence, the fact that inflation expectations only gradually incorporate the changes in the actual inflation rate implies that the formation of firms' inflation expectations has an aspect that cannot be described solely by FIRE.

3.2 Examination Based on Forecast Errors

The results in the previous subsection suggest that, although the formation of Japanese firms' inflation expectations has a forward-looking aspect, its mechanism cannot be described solely by FIRE. In this subsection, employing a framework proposed by Coibion and Gorodnichenko (2015), we statistically test whether FIRE alone can explain the formation of firms' inflation expectations.

In the testing framework proposed by Coibion and Gorodnichenko (2015), the empirical validity of FIRE is examined by testing whether the forecast errors of aggregate-level inflation expectations correlate with their past revisions. The reason why the empirical validity of FIRE can be tested by checking the correlation is as follows. If all firms, as FIRE presupposes, make full use of all the observable information in forming their expectations for the 1-year-ahead (year-on-year) inflation rate π_{t+4}, the inflation expectation of each firm equals the mathematical expectation of the inflation rate conditional on the information at period t, i.e. $E_t\pi_{t+4}$, and thus the average inflation expectation of the firms also equals this value. In this case, theoretically, the aggregate-level forecast error of inflation expectations, $\pi_{t+4} - E_t\pi_{t+4}$, should not correlate with any variables that are observable at period t.[15] Hence, if the forecast error correlates with the revision of inflation expectations made at period t, which is obviously observable at period t, it follows that FIRE does not hold for all firms.

In this subsection, following Coibion and Gorodnichenko (2015), we examine the correlation between the forecast errors and the revisions of inflation expectations by estimating the following equation:

$$\pi_{t+4} - \pi^{\mathrm{e}}_{t+4|t} = c + \beta(\pi^{\mathrm{e}}_{t+4|t} - \pi^{\mathrm{e}}_{t+4|t-1}) + \varepsilon_{t+4}, \tag{2}$$

[15] In fact, for an arbitrary variable X_s ($s \leq t$) that is observable at period t, it holds that $E[(\pi_{t+4} - E_t\pi_{t+4})X_s] = E[E_t[\pi_{t+4} - E_t\pi_{t+4}]X_s] = 0$ by the law of iterated expectations.

where π_{t+4} is the actual inflation rate one year after period t (CPI, all items, year-on-year percent change), and $\pi^{e}_{t+4|t}$ is the average of the 1-year-ahead (i.e. 4-quarter-ahead) inflation expectations that are formed at period t.[16] Hence the left-hand side of the equation is the forecast error of 1-year-ahead inflation expectations, whereas the term in parentheses on the right-hand side of the equation is the revision (from the previous quarter to the current quarter) of 1-year-ahead inflation expectations.[17]

The coefficient β in equation (2) is zero (that is, the forecast error and the revision are uncorrelated) if and only if FIRE holds for all firms. Therefore, if $\beta = 0$ is rejected in the estimation results of equation (2), indicating the forecast error and the forecast revision are correlated, then the null hypothesis that "FIRE holds for all firms" is rejected.

We could set up equations similar to equation (2) for 3-year- and 5-year-ahead inflation expectations as well. However, because the *Tankan* data of inflation expectations are relatively short in the time series dimension, the number of observations of the forecast errors on the left-hand side of the equations would be very limited for 3-year- and 5-year-ahead inflation expectations. Therefore, here we focus the analysis only on 1-year-ahead expectations.

Panel (1) of Table 1 shows the estimation results of equation (2) for each of 9 industry-size groups (3 industry groups and 3 size groups; 9 industry-size groups in total), using 1-year-ahead average inflation expectations.[18] The sample period is from 2015Q1 to 2019Q1. For all groups, the estimates of β are statistically significant, and thus the null hypothesis of $\beta = 0$ is rejected. This result implies that FIRE does not in general hold for the formation of firms' inflation expectations.

However, the estimation results for each industry-size group may not necessarily be sufficiently reliable, because the number of observations is limited to 13 in these cases. To complement this, we also estimate equation (2) with panel data of the 9 industry-size groups (i.e. the cross-sectional dimension is 9). Panel (2) of Table 1 shows the result of

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[16] We use "CPI (all items)" here because the *Tankan* does not ask the firms to exclude any specific items such as fresh food in giving their inflation expectations.

[17] In the *Tankan*, since the forecast horizons are fixed at 1 year (4 quarters), 3 years (12 quarters), and 5 years (20 quarters), the data corresponding to $\pi^{e}_{t+4|t-1}$ (the 5-quarter-ahead forecast in period $t-1$) on the right-hand side of equation (2) does not exist. In this paper, we use the data corresponding to $\pi^{e}_{t+3|t-1}$ (the 4-quarter-ahead forecast in period $t-1$) in place of $\pi^{e}_{t+4|t-1}$.

[18] We checked that none of the estimates of constant c, which are omitted in the table, are statistically significant.

the panel-data regression.[19] The estimate of β is again statistically significant, and the null hypothesis of $\beta = 0$ is rejected in this case as well.

These results indicate that, on average, FIRE is not empirically valid for the firms' inflation expectations. Of course, this does not deny the possibility that FIRE can correctly describe the formation of inflation expectations by some of the firms. However, the results in this subsection, as well as the results of the panel VAR in the previous subsection, strongly suggest that the mechanism of the formation of firms' inflation expectations cannot be described solely by FIRE.

Then, what other hypotheses can explain the formation of firms' inflation expectations? In this regard, Coibion and Gorodnichenko (2015) show that β in equation (2) is positive under either the noisy information hypothesis or the sticky information hypothesis. Their argument is as follows. First, under the noisy information hypothesis, firms take account of the fact that observed data of the inflation rate contain noise, and they update only some fraction G $(0 < G < 1)$ of their expectations using the information contained in the inflation rate, while they keep the remaining fraction $1 - G$ of their expectations unchanged from the previous period. In this case, the average forecast error of inflation expectations can be written as

$$\pi_{t+4} - \pi^{\mathrm{e}}_{t+4|t} = \frac{1-G}{G}(\pi^{\mathrm{e}}_{t+4|t} - \pi^{\mathrm{e}}_{t+4|t-1}) + \nu_{t+4}, \tag{3}$$

where ν_{t+4} is an error term. Second, under the sticky information hypothesis, a fraction $1 - \lambda$ of firms update their information and revise their expectations by making full use of it, whereas the remaining fraction λ of firms keep their expectations unchanged from the previous period. In this case, the average forecast error of inflation expectations can be written as

$$\pi_{t+4} - \pi^{\mathrm{e}}_{t+4|t} = \frac{\lambda}{1-\lambda}(\pi^{\mathrm{e}}_{t+4|t} - \pi^{\mathrm{e}}_{t+4|t-1}) + \nu_{t+4}. \tag{4}$$

[19] To be more specific, the equation for the panel-data regression is as follows:

$$\pi_{t+4} - \pi^{\mathrm{e},i}_{t+4|t} = \gamma_i + \beta(\pi^{\mathrm{e},i}_{t+4|t} - \pi^{\mathrm{e},i}_{t+4|t-1}) + \varepsilon_{i,t+4},$$

where i is an index for industry-size group, and the error term $\varepsilon_{i,t+4}$ captures factors other than the revision of expectations $(\pi^{\mathrm{e},i}_{t+4|t} - \pi^{\mathrm{e},i}_{t+4|t-1})$ and fixed effects (γ_i) that affect forecast errors. Because the forecast errors can be correlated with each other across the cross-sectional dimension, for this panel-data regression we employ General FGLS to take into account possible cross-sectional correlations between the error terms. For details of General FGLS, see Wooldridge (2010, Chapter 10).

Hence, the result shown in Table 1 that β is positive to a statistically significant extent suggests that either the noisy information hypothesis or the sticky information hypothesis may be empirically valid.

Furthermore, using the estimate of β, we can quantify the degree of information rigidity due to noisy information or sticky information. That is, comparing equation (2) with equations (3) and (4) reveals that both $1 - G$, which is the weight that firms place on the previous period's expectations under the noisy information hypothesis, and λ, which is the fraction of firms that keep their expectations unchanged under the sticky information hypothesis, correspond to $\beta/(1 + \beta)$. Therefore, under either hypothesis, the degree of information rigidity can be measured with $\beta/(1 + \beta)$.

The value of $\beta/(1+\beta)$ for each estimate of β is shown in the bottom row of each panel in Table 1. For instance, the value calculated using the estimate of β obtained by the panel-data regression is 0.73. From the viewpoint of the noisy information hypothesis, this implies that firms incorporate only 27% (= 100% − 73%) of newly acquired information into their inflation expectations because of the presence of noise in the information. Or, from the viewpoint of the sticky information hypothesis, this implies that in each period only 27% of the firms revise their expectations. Regarding the latter, Figure 5 shows the frequency of revisions of inflation expectations for our sample data, calculated in the same way as that of Uno et al. (2018) whose sample period is from March 2014 to September 2017. The frequency for 1-year-ahead inflation expectations is 4 out of 16 during the sample period. This is consistent with the result based on the estimate of β which we mentioned above.[20]

These results of the examination based on the forecast errors suggest that the noisy information hypothesis and the sticky information hypothesis are likely to be empirically valid for the formation of firms' inflation expectations. In the next section, we use firm-level data of inflation expectations to examine the empirical validity of these two hypotheses.

[20] The fact that a firm does not revise its inflation expectations does not necessarily mean that the firm does not update its information set. Even when a firm updates its information set, it can keep its expectations unchanged if the new information simply confirms its expectations. Therefore, the frequency of revisions of inflation expectations discussed here should be interpreted as a lower bound of the frequency of information updates.

4 Examination of the Empirical Validity of the Noisy Information and Sticky Information Hypotheses

In this section, we examine the empirical validity of the noisy information and sticky information hypotheses via a dynamic panel regression analysis of firm-level data. In doing so, we first explore what features firm-level data of inflation expectations would exhibit under these hypotheses, and then set up an empirical framework that can capture such features. After that, we discuss the estimation results.

4.1 Implications of Noisy Information and Sticky Information Hypotheses on Firm-Level Data

In exploring what features would appear in the firm-level data of inflation expectations under the noisy information and sticky information hypotheses, we assume that the economy can be represented by the following model with a relatively simple structure.

$$\pi_t = AX_t^* + \eta_t^\pi, \tag{5}$$

$$X_t^* = BX_{t-1}^* + \eta_t^X, \tag{6}$$

where π_t denotes the inflation rate, X_t^* other macroeconomic variables, η_t^π a shock to the inflation rate, and η_t^X shocks to the macroeconomic variables excluding the inflation rate. A and B are coefficient matrices.

4.1.1 Noisy Information Hypothesis

Under the noisy information hypothesis, firms extract information that is useful for forming their inflation expectations not only from information on macroeconomic conditions but also from firm-specific information such as the purchase price of raw materials. Below, we show this by using a model that extends the model of Coibion and Gorodnichenko (2015). Appendix contains details of the derivations of the key equation and related discussions.

Assume that firms cannot observe the macroeconomic variables X_t^* directly, and that they can only observe the macroeconomic indices X_t that contain noise ε_t^X as follows.[21]

$$X_t = X_t^* + \varepsilon_t^X. \tag{7}$$

Also, assume that the firm i's idiosyncratic variables $Y_{i,t}$, such as input prices and demand conditions the firm faces, are driven by the macroeconomic variables X_t^* as well as firm-level shocks $\eta_{i,t}^Y$ as follows.

$$Y_{i,t} = CX_t^* + \eta_{i,t}^Y, \tag{8}$$

where C is a coefficient matrix. Hence, the firm's idiosyncratic variables $Y_{i,t}$ also contain information about the macroeconomic variables X_t^*.

Under this setting, a firm has to estimate the unobservable macroeconomic variables X_t^* using the observed macroeconomic indices X_t, the actual inflation rate π_t, and the idiosyncratic variables $Y_{i,t}$ in predicting future inflation rates.[22] The Kalman filter is known to be the optimal way to make an estimate and a prediction in this environment. The estimate of X_t^* obtained via the Kalman filter is given by

$$E_{i,t}X_t^* = G_{i,t}^X X_t + G_{i,t}^\pi \pi_t + G_{i,t}^Y Y_{i,t} + (I - G_{i,t}^X)E_{i,t-1}X_t^* - G_{i,t}^\pi E_{i,t-1}\pi_t - G_{i,t}^Y E_{i,t-1}Y_{i,t}, \tag{9}$$

where $G_{i,t}^X$, $G_{i,t}^\pi$, and $G_{i,t}^Y$ are matrices that represent the weights placed by firm i on the observable variables X_t, π_t, and $Y_{i,t}$, respectively, and $E_{i,t}$ is the mathematical expectation operator conditional on the information available to firm i at period t.

Substituting equations (5) and (8) into the fifth and sixth terms in the right-hand side of equation (9), multiplying both sides by AB^h, and applying equations (5) and (6) yields the following equation for h-period-ahead inflation expectations:

$$E_{i,t}\pi_{t+h} = (I - G_{i,t}^X - G_{i,t}^\pi A - G_{i,t}^Y C)E_{i,t-1}\pi_{t+h} + AB^h(G_{i,t}^X X_t + G_{i,t}^\pi \pi_t + G_{i,t}^Y Y_{i,t}). \tag{10}$$

[21]In the seminal work on the noisy information hypothesis by Lucas (1972), noise in a macroeconomic variable (nominal amount of money) is assumed to disappear in one period. In contrast, noise contained in economic variables does not completely disappear in our setting. Our setting is close to that of Woodford (2003), who extended Lucas' model.

[22]Imagine, for example, a situation where the inflation rate π_t and the input prices $Y_{i,t}$ in firm i's industy are both affected by the output gap X_t^*, which cannot be observed directly and therefore has to be estimated by the observed data (X_t, π_t, $Y_{i,t}$).

The implications we can draw from this equation, derived under the noisy information hypothesis, are threefold. First, firms' inflation expectations ($E_{i,t}\pi_{t+h}$) depend on their own expectations formed in the previous period ($E_{i,t-1}\pi_{t+h}$). Second, the firms' inflation expectations are affected by current macroeconomic information (X_t and π_t).[23] Third, firms' inflation expectations are also affected by their own idiosyncratic information ($Y_{i,t}$). In particular, under the rational inattention hypothesis, which is a variant of the noisy information hypothesis, economic agents with limited capacity for information processing focus their attention primarily on information useful for their own business, and therefore firms pay more attention to micro-level information $Y_{i,t}$ that directly affects their business than to macroeconomic information, X_t and π_t.[24]

Hence, in order to capture the features of expectations formation that would be exhibited under the noisy information hypothesis in a panel regression analysis, we should include lagged inflation expectations, macroeconomic variables, and firm-specific variables as explanatory variables in the regression.

It can also be seen from equation (10) that, if the macroeconomic variables X_t^* are stationary, as the forecast horizon becomes longer (h becomes larger), B^h on the right-hand side of the equation converges to the zero matrix, and thus the current variables, including the firm-specific variables, become less likely to influence inflation expectations. Therefore, even under the noisy information hypothesis, the estimates of the coefficients on current variables may not necessarily be statistically significant for long-term inflation expectations.

4.1.2 Sticky Information Hypothesis

Under the sticky information hypothesis, because of the presence of the cost of information updates, it can be optimal for firms to leave their expectations unchanged without acquiring new information relevant to forming expectations. The optimal behavior of a firm in such a situation is modeled by Reis (2006).[25] In this model, a firm facing the cost

[23] Past macroeconomic information indirectly affects current inflation expectations through the past expectations formed in the previous period ($E_{i,t-1}\pi_{t+h}$).

[24] Maćkowiak and Wiederholt (2009) apply the rational inattention hypothesis to firms' price setting problem, and theoretically show that prices become less responsive to shocks in nominal demand as firms focus their attention on micro-level information that directly affects their own business.

[25] In the seminal paper of Mankiw and Reis (2002), who proposed the sticky information hypothesis, a certain fraction of firms are assumed to leave their expectations unchanged, but the mechanism by which

of information updates determines the timing of the information update to maximize the discounted sum of its future profits. Reis (2006) proves that a firm's optimal timing of its information update depends on the size of the cost of information updates. Specifically, if the ratio of firm i's cost of information updates over its current profit is κ_i, the optimal duration for keeping its information set unchanged is proportional to $\sqrt{\kappa_i}$.

Thus, under the sticky information hypothesis, firms do not always acquire information and may leave their inflation expectations unchanged, although the frequency of firms' revision of expectations can differ depending on the size of the cost of information updates. Therefore, firms' inflation expectations can depend on their past expectations.

If firms update information, however, they form expectations rationally based on equations (5) and (6). More specifically, their inflation expectations equal $E_t \pi_{t+h} = AB^h X_t^*$ (note that X_t^* is directly observable under this hypothesis while it is not under the noisy information hypothesis). That is, these firms use only the macroeconomic variables X_t^* in forming their inflation expectations.

Hence, in order to capture the features of expectations formation that would be exhibited under the sticky information hypothesis in a panel regression, we should include lagged inflation expectations and macroeconomic variables as explanatory variables in the regression.

4.2 Estimation Framework

The discussion in the previous subsection reveals that, in order to capture the features of the formation of inflation expectations that would be exhibited under the noisy information and sticky information hypotheses in a panel regression, we should use lagged inflation expectations, macroeconomic variables, and idiosyncratic variables as explanatory variables in the regression. Therefore, in what follows, we examine the empirical validity of the two hypotheses by estimating the following equation using a dynamic panel regression method.

$$\pi^{\mathrm{e}}_{i,t} = \alpha_1 \pi^{\mathrm{e}}_{i,t-1} + \alpha_2 \pi^{\mathrm{e}}_{i,t-2} + \beta' x_{i,t-1} + \alpha_i^{FE} + T_t + \varepsilon_{i,t}, \tag{11}$$

each firm chooses not to change its expectations is not explicitly modeled. The analysis of Reis (2006) complements that of Mankiw and Reis (2002) by theoretically showing that the presence of the cost of information updates makes it optimal for firms to leave their expectations unchanged.

where $\pi^{\mathrm{e}}_{i,t}$ denotes firm i's 1-year- or 5-year-ahead inflation expectations at period t, and $\pi^{\mathrm{e}}_{i,t-1}$ and $\pi^{\mathrm{e}}_{i,t-2}$ are their lagged values.[26] $x_{i,t}$ is a vector of judgment items in the *Tankan*, which captures firm-specific time-varying information. α_i^{FE} is the fixed effect in the cross-sectional dimension, which captures firm-specific time-invariant information. T_t denotes the fixed effect in the time-series dimension, which captures macroeconomic information.

In our baseline-case estimation, we use as explanatory variables four judgment items that are thought to be important for firms' price settings, as Koga et al. (2019) suggest, namely, ("current" judgments of) "domestic supply and demand conditions," "change in input prices," "change in output prices," and "employment conditions." To check the robustness of the estimation results, however, we will later re-estimate the model including additional judgment items. The answer to each judgment item is transformed into a numerical value, +1, 0, or –1. Table 2 shows the correspondence between these numerical values and the available answer options. The options that are considered as indicating improvements in economic or financial conditions are transformed into +1 for each judgment item. Because inflation expectations are likely to rise when economic or financial conditions improve, we expect the coefficients of the judgment items to be estimated in positive values.

To deal with potential endogeneity problems, we take a one-period lag for each judgment item. We also employ the system GMM method proposed by Blundell and Bond (1998) in conducting the dynamic panel-data regression. As for the instrument variables for the GMM, we choose the combinations of lagged variables for which the information criterion based on the J-statistic proposed by Andrews and Lu (2001) is minimized.[27] The sample period is from 2015Q1 to 2019Q1.

[26] In order to just capture the features of the formation of inflation expectations that would be exhibited under the noisy information and sticky information hypotheses, it is enough to include a one-period lag of the inflation expectations as an explanatory variable in the regression. However, a close look at the firm-level data reveals that the inflation expectations tend to depend on a two-period lag as well as a one-period lag. To take into account this observed feature of the data, we include the two-period lag of inflation expectations as an explanatory variable in the regression.

[27] Andrews and Lu (2001) point out that the Bayesian information criterion (BIC) tends to select more appropriate models than the Akaike information criterion (AIC) does when, as in our case, the sample size in the cross-sectional dimension is large. Thus, in this paper we use BIC rather than AIC as the information criterion.

4.3 Estimation Results

Table 3 shows the estimation results of the baseline case with the four judgment items. For both 1-year- and 5-year-ahead expectations, the estimated coefficients on the lags of inflation expectations are statistically significant, consistent with both the noisy information and sticky information hypotheses.

On the other hand, for the judgment items, the results differ across time horizons of inflation expectations and firm sizes. Below we will discuss the results by time horizons of inflation expectations.

4.3.1 1-Year-Ahead Inflation Expectations

As for 1-year-ahead inflation expectations of small firms, the estimated coefficients on input prices, output prices, and domestic demand are statistically significant.[28] This result suggests the empirical validity of the noisy information hypothesis, especially of the rational inattention hypothesis. In addition, as we expected, the coefficients are estimated to be positive. Our interpretations of the estimation results for the coefficients are as follows.

First, the reason why small firms with rising input prices tend to have higher inflation expectations could be that small firms extract information on price developments around them from input prices and use the information in forming their inflation expectations. Second, small firms with rising output prices also tend to have higher inflation expectations possibly because they think that, since they are able to (or forced to) raise output prices, their competitors will also raise their prices, and expect that this will result in a rise in the general price level. Third, small firms that recognize excess demand in their domestic markets have higher inflation expectations probably because they think that the tight demand in the markets will lead many firms to raise their prices.

In contrast to the results for small firms, none of the estimated coefficients on the judgment items are statistically significant for large firms. One possible interpretation of this result is that the rational inattention hypothesis does not hold for large firms, but

[28] Economic Analysis Group of the Bank of Japan (2017), who applied machine learning techniques to the *Tankan* data to examine factors that affect firms' inflation expectations, also report that 1-year-ahead inflation expectations of firms are affected by their judgments regarding input prices, output prices, and financial position.

there are two other possible interpretations.

The first interpretation is actually based on the rational inattention hypothesis. Under this hypothesis, firms with limited capacity for information processing focus their attention primarily on information that affects their business, and they form their inflation expectations using such information. Hence, if macroeconomic conditions have a relatively large impact on their business, large firms may not pay much attention to their firm-specific information while paying much more attention to macroeconomic information. Based on this interpretation, the fact that the judgment items are not statistically significant for large firms does not necessarily contradict the rational inattention hypothesis (or the noisy information hypothesis that includes it as a variant), but rather can be regarded as consistent with the rational inattention hypothesis.

The second interpretation is that the size of the cost of decision-making depends on firm size. As the empirical study by Zbaracki et al. (2004) suggests, a large firm may incur large costs for internal decision-making processes such as coordination among internal divisions, and thus it can take a long time for the organization as a whole to determine its inflation expectations.[29] Therefore, in a large firm, even when its own business conditions change, the person responsible for answering the *Tankan* survey may have to leave the answer for inflation expectations unchanged until the organization as a whole determines its official inflation expectations.[30] On the other hand, small firms may face smaller decision-making costs than large firms do, making it easier for them to change their inflation expectations in a short period of time. Because of this, small firms may be able to change their answers for inflation expectations in the survey (together with those for the judgment items) more easily by taking into account the ongoing changes in their business conditions.

[29] Zbaracki et al. (2004) conduct a case study on a large firm in the U.S. According to the results, the costs related to acquiring information and revising its economic forecasts (the total cost of information gathering, decision-making, and internal communication) amount to 4.6% of their net profits.

[30] As we noted in footnote 5, for large firms, the share of firms that chose a numeric option for their 1-year-ahead expectation is 76%, which is lower than 87% for medium-sized firms and 89% for small firms (as of March 2019). In addition, as shown in Figure 5, the frequency of expectation revision of large firms is lower than that of smaller firms. These features of the data may also reflect that the costs of decision-making increase as firm size increases.

4.3.2 5-Year-Ahead Expectations

As for 5-year-ahead inflation expectations, the estimated coefficients on all judgment items are statistically insignificant for both large and small firms.[31] This result may simply reflect the possibility that, in forming long-term inflation expectations, firms do not find information on their current business conditions useful, due to the intrinsically high degree of uncertainty about the long-term future. Indeed, as we discussed in Section 4, even under the noisy information hypothesis, current variables may not be statistically significant for long-term inflation expectations. Therefore, this result does not necessarily imply that the noisy information hypothesis fails to hold for the firms' inflation expectations.

4.4 Robustness Check: the Case with Additional Judgment Items

In the baseline case, we used as explanatory variables the four judgment items that are thought to be important for firms' price setting behavior. However, in forming their inflation expectations, firms might also use information that is contained in other judgment items.

To check the robustness of the results of the baseline case with respect to this point, we re-estimate the model including additional judgment items as explanatory variables, using the data for all firms. The additional items are ("current" judgments on) "business conditions," "production capacity," "financial position," and "change in interest rate on loans."[32]

Table 4 shows the estimation results of the case with the additional judgment items. For both 1-year- and 5-year-ahead inflation expectations, there is no dramatic change in the values and statistical significance of the estimated coefficients on the lagged inflation expectations and the judgment items that were already used in the baseline case. In addition, all of the estimated coefficients on the additional judgment items are statistically insignificant.

[31] Economic Analysis Group of the Bank of Japan (2017), who applied machine learning techniques to the *Tankan* data, also report that judgment items do not have a large influence on long-term inflation expectations.

[32] We do not use some judgment items such as "overseas supply and demand conditions" and "inventory level of finished goods and merchandise," for which the number of respondent firms is limited.

Hence, we conclude that the four judgment items used in the baseline case capture most of the information that firms use in forming their inflation expectations.

5 Conclusion

In this paper, using both semi-aggregate and firm-level data of survey inflation expectations of Japanese firms, we examine the empirical validity of three hypotheses on inflation expectations formation: the FIRE, noisy information, and sticky information hypotheses.

Our main findings are as follows. First, the results of our panel VAR analysis using semi-aggregate data show that, while shocks to firms' long-term expectations propagate to their short-term expectations consistently with FIRE, firms' inflation expectations are not fully consistent with FIRE in that they tend to incorporate the changes in the actual inflation rate only gradually. Second, the forecast errors of semi-aggregate inflation expectations correlate with the past revisions of expectations, implying a rejection of the null hypothesis that FIRE holds for all firms. Third, the results of firm-level dynamic panel regressions show that firms' inflation expectations depend to a great extent on their past expectations, which is consistent with both the noisy information and sticky information hypotheses. The regression results also show that the short-term expectations of small firms are influenced by their perception of their own business conditions, which is consistent with the noisy information hypothesis, especially the rational inattention variant. These findings suggest that firms in Japan form their inflation expectations in a complex manner that cannot be described by a single theory.

The conclusion of this paper that firms' formation of inflation expectations cannot be described by a single theory provides an important suggestion as to how to build macroeconomic models that are consistent with the actual data of firms' inflation expectations. An important topic for future research is to explore the implications for macroeconomic dynamics of the various hypotheses on the formation of inflation expectations, such as the noisy information and sticky information hypotheses, by building macroeconomic models that incorporate these hypotheses to successfully explain the actual data of inflation expectations.[33]

[33] The paper by Kitamura and Tanaka (2019) is one example of recent work in this direction. Using the data for Japan, including the aggregate inflation expectations in the *Tankan*, they estimate a small-size

Appendix. Formation of Inflation Expectations under the Noisy Information Hypothesis

In this appendix, we show that, under the settings of subsection 4-1, the estimate of macroeconomic variables X_t^* via the Kalman filter is given by equation (9), and this estimate (and the associated inflation expectations) depends on micro-level as well as macro-level information.

For convenience, we summarize the settings of subsection 4-1 below.

$$\pi_t = AX_t^* + \eta_t^\pi. \tag{5}$$

$$X_t^* = BX_{t-1}^* + \eta_t^X. \tag{6}$$

$$X_t = X_t^* + \varepsilon_t^X. \tag{7}$$

$$Y_{i,t} = CX_t^* + \eta_{i,t}^Y. \tag{8}$$

A-1. Derivation of Equation (9)

Defining $\xi_{i,t} \equiv (X_t^*, \pi_t, Y_{i,t})'$, $Z_{i,t} \equiv (X_t, \pi_t, Y_{i,t})'$, and $w_t \equiv (\varepsilon_t^X, 0, 0)'$, equations (5)- (8) can be cast into the following state-space representation:

$$\begin{aligned} &\text{State transition equation:} \quad && \xi_{i,t} = F\xi_{i,t-1} + v_{i,t}, \\ &\text{Observation equation:} && Z_{i,t} = \xi_{i,t} + w_t, \end{aligned}$$

where

$$F \equiv \begin{bmatrix} B & O & O \\ AB & O & O \\ CB & O & O \end{bmatrix}, \quad v_{i,t} \equiv \begin{bmatrix} I & O & O \\ A & I & O \\ C & O & I \end{bmatrix} \begin{bmatrix} \eta_t^X \\ \eta_t^\pi \\ \eta_{i,t}^Y \end{bmatrix}.$$

macroeconomic model that incorporates FIRE, rational inattention, and sticky information, and report that each one of the three hypotheses has a role to play in explaining the mechanism of the formation of firms' inflation expectations.

Assume that η_t^X, η_t^π, $\eta_{i,t}^Y$, and ε_t^X are mutually uncorrelated and

$$\begin{bmatrix} \eta_t^X \\ \eta_t^\pi \\ \eta_{i,t}^Y \\ \varepsilon_t^X \end{bmatrix} \sim N(O, \Lambda), \quad \Lambda \equiv \begin{bmatrix} \Sigma_X & O & O & O \\ O & \sigma_\pi^2 & O & O \\ O & O & \Sigma_Y & O \\ O & O & O & \Omega \end{bmatrix}.$$

Then the covariance matrices of $v_{i,t}$ and w_t can be written as:

$$E[v_{i,t}v_{i,t}'] \equiv Q = \begin{bmatrix} \Sigma_X & \Sigma_X A' & \Sigma_X C' \\ A\Sigma_X & A\Sigma_X A' + \sigma_\pi^2 & A\Sigma_X C' \\ C\Sigma_X & C\Sigma_X A' & C\Sigma_X C' + \Sigma_Y \end{bmatrix},$$

$$E[w_t w_t'] \equiv R = \begin{bmatrix} \Omega & O & O \\ O & O & O \\ O & O & O \end{bmatrix}.$$

Under the above state-space representation, the estimate $E_{i,t}\xi_{i,t}$ obtained via the Kalman filter is given by:

$$\begin{aligned} E_{i,t}\xi_{i,t} &= E_{i,t-1}\xi_{i,t} + \underbrace{P_{i,t|t-1}(P_{i,t|t-1} + R)^{-1}}_{\equiv G_{i,t}}(Z_{i,t} - E_{i,t-1}\xi_{i,t}) \\ &= (I - G_{i,t})E_{i,t-1}\xi_{i,t} + G_{i,t}Z_{i,t}, \end{aligned} \tag{A.1}$$

where $P_{i,t|t-1} \equiv E[(\xi_{i,t} - E_{i,t-1}\xi_{i,t})(\xi_{i,t} - E_{i,t-1}\xi_{i,t})']$ is the covariance matrix of the forecast errors of $\xi_{i,t}$.[34]

For notational simplicity, hereafter we abbreviate $E_{i,t}$ to E_t by omitting the firm-index i from the covariance matrix $P_{i,t|t-1}$ and the Kalman gain $G_{i,t}$.

Partitioning the matrix G_t into

$$G_t \equiv P_{t|t-1}(P_{t|t-1} + R)^{-1} = \begin{bmatrix} G_t^X & G_t^\pi & G_t^Y \\ G_{21,t} & G_{22,t} & G_{23,t} \\ G_{31,t} & G_{32,t} & G_{33,t} \end{bmatrix},$$

[34] See, for example, Hamilton (1994) for details on the Kalman filter.

and substituting this into equation (A.1), we obtain the following equation:

$$E_t X_t^* = G_t^X X_t + G_t^\pi \pi_t + G_t^Y Y_{i,t} + (I - G_t^X) E_{t-1} X_t^* - G_t^\pi E_{t-1} \pi_t - G_t^Y E_{t-1} Y_{i,t}, \quad \text{(A.2)}$$

which is equation (9) in the main text.

A-2. Dependence on Macro- and Micro-Level Information

We show that G_t^X, G_t^π, and G_t^Y in equation (A.2) are all non-zero matrices, that is, the estimate of the macroeconomic variable X_t^*, $E_t X_t^*$, depends on X_t, π_t, and $Y_{i,t}$ in general.

As a preparation, let us obtain an expression of the covariance matrix $P_{t|t-1}$ using the sub-matrices of $P_{t-1|t-1} \equiv E[(\xi_{i,t-1} - E_{t-1}\xi_{i,t-1})(\xi_{i,t-1} - E_{t-1}\xi_{i,t-1})']$, which is the covariance matrix of the forecast errors of $\xi_{i,t-1}$. In the framework of the Kalman filter, it is known that $P_{t|t-1}$ is updated by the following equation:

$$P_{t|t-1} = F P_{t-1|t-1} F' + Q, \quad \text{(A.3)}$$

Partitioning $P_{t|t-1}$ and $P_{t-1|t-1}$ into sub-matrices as

$$P_{t|t-1} \equiv \begin{bmatrix} P_{11,t-1} & P_{12,t-1} & P_{13,t-1} \\ P_{21,t-1} & P_{22,t-1} & P_{23,t-1} \\ P_{31,t-1} & P_{32,t-1} & P_{33,t-1} \end{bmatrix}, \quad P_{t-1|t-1} \equiv \begin{bmatrix} \Upsilon_{11,t-1} & \Upsilon_{12,t-1} & \Upsilon_{13,t-1} \\ \Upsilon_{21,t-1} & \Upsilon_{22,t-1} & \Upsilon_{23,t-1} \\ \Upsilon_{31,t-1} & \Upsilon_{32,t-1} & \Upsilon_{33,t-1} \end{bmatrix},$$

and expanding the right-hand side of equation (A.3), we obtain an expression of $P_{t|t-1}$ with the sub-matrices of $P_{t-1|t-1}$ as follows.

$$P_{t|t-1} = \begin{bmatrix} P_{11,t-1} & P_{12,t-1} & P_{13,t-1} \\ P_{21,t-1} & P_{22,t-1} & P_{23,t-1} \\ P_{31,t-1} & P_{32,t-1} & P_{33,t-1} \end{bmatrix}$$

$$= \begin{bmatrix} B\Upsilon_{11,t-1}B' + \Sigma_X & B\Upsilon_{11,t-1}B'A' + \Sigma_X A' & B\Upsilon_{11,t-1}B'C' + \Sigma_X C' \\ AB\Upsilon_{11,t-1}B' + A\Sigma_X & AB\Upsilon_{11,t-1}B'A' + A\Sigma_X A' + \sigma_\pi^2 & AB\Upsilon_{11,t-1}B'C' + A\Sigma_X C' \\ CB\Upsilon_{11,t-1}B' + C\Sigma_X & CB\Upsilon_{11,t-1}B'A' + C\Sigma_X A' & CB\Upsilon_{11,t-1}B'C' + C\Sigma_X C' + \Sigma_Y \end{bmatrix}. \quad \text{(A.4)}$$

(1) Proving that $P_{12,t-1} \neq O$ and $P_{13,t-1} \neq O$

First we show that $P_{12,t-1} \neq O$ and $P_{13,t-1} \neq O$ in equation (A.4). Left-multiplying the (1,2) element of equation (A.4) by A and the (1,3) element of the equation by C yields

$$\begin{aligned} AP_{12,t-1} &= AB\Upsilon_{11,t-1}B'A' + A\Sigma_X A', \\ CP_{13,t-1} &= CB\Upsilon_{11,t-1}B'C' + C\Sigma_X C'. \end{aligned}$$

Suppose that $P_{12,t-1} = O$ or $P_{13,t-1} = O$ holds. Then either of the followings holds:

$$\begin{aligned} AB\Upsilon_{11,t-1}B'A' &= -A\Sigma_X A', \\ CB\Upsilon_{11,t-1}B'C' &= -C\Sigma_X C'. \end{aligned}$$

However, in either equation, the matrix on the left-hand side is positive definite, whereas the matrix on the right-hand side is negative definite. This is a contradiction.[35] Hence, we have $P_{12,t-1} \neq O$ and $P_{13,t-1} \neq O$.

(2) Derivation of an Expression of G_t Using the Sub-Matrices of $P_{t|t-1}$

Next, let us obtain an expression of $G_t \equiv P_{t|t-1}(P_{t|t-1} + R)^{-1}$ using the sub-matrices of $P_{t|t-1}$. The definition of G_t can be rewritten as

$$\begin{aligned} G_t &\equiv P_{t|t-1}(P_{t|t-1} + R)^{-1} = \{(P_{t|t-1} + R) - R\}(P_{t|t-1} + R)^{-1} \\ &= I - \underbrace{R(P_{t|t-1} + R)^{-1}}_{\equiv \Theta_{t-1}} = I - R\Theta_{t-1}. \end{aligned} \tag{A.5}$$

By partitioning G_t, Θ_{t-1}, and $P_{t|t-1}$ into

$$G_t = \begin{bmatrix} G_t^X & G_t^\pi & G_t^Y \\ G_{21,t} & G_{22,t} & G_{23,t} \\ G_{31,t} & G_{32,t} & G_{33,t} \end{bmatrix} \equiv \begin{bmatrix} G_t^X & \widetilde{G}_{12,t} \\ \widetilde{G}_{21,t} & \widetilde{G}_{22,t} \end{bmatrix},$$

[35] Rigorous arguments are as follows. Suppose that $AB\Upsilon_{11,t-1}B'A' = -A\Sigma_X A'$ holds. Take an arbitrary vector $x \neq 0$ such that $A'x \neq 0$. Then, since $B\Upsilon_{11,t-1}B'$ is non-negative definite, $x'AB\Upsilon_{11,t-1}B'A'x \geq 0$. On the other hand, since Σ_X is positive definite, $x'(-A\Sigma_X A')x = -(A'x)'\Sigma_X(A'x) < 0$, yielding a contradiction. If we instead suppose that $CB\Upsilon_{11,t-1}B'C' = -C\Sigma_X C'$, a contradiction can be obtained by a similar argument.

$$\Theta_{t-1} = \begin{bmatrix} \Theta_{11,t-1} & \Theta_{12,t-1} \\ \Theta_{21,t-1} & \Theta_{22,t-1} \end{bmatrix},$$

$$P_{t|t-1} = \begin{bmatrix} P_{11,t-1} & P_{12,t-1} & P_{13,t-1} \\ P_{21,t-1} & P_{22,t-1} & P_{23,t-1} \\ P_{31,t-1} & P_{32,t-1} & P_{33,t-1} \end{bmatrix} \equiv \begin{bmatrix} P_{11,t-1} & \widetilde{P}_{12,t-1} \\ \widetilde{P}_{21,t-1} & \widetilde{P}_{22,t-1} \end{bmatrix},$$

respectively, and substituting these into G_t and Θ_{t-1} in equation (A.5), we obtain the following equation:

$$G_t = I - \begin{bmatrix} \Omega & O \\ O & O \end{bmatrix} \begin{bmatrix} \Theta_{11,t-1} & \Theta_{12,t-1} \\ \Theta_{21,t-1} & \Theta_{22,t-1} \end{bmatrix} = \begin{bmatrix} I - \Omega\Theta_{11,t-1} & -\Omega\Theta_{12,t-1} \\ O & I \end{bmatrix}. \quad \text{(A.6)}$$

Applying the formula of the inverse matrix for 2×2 partitioned matrices to $\Theta_{t-1} \equiv (P_{t|t-1} + R)^{-1}$, we have

$$\begin{aligned} & \begin{bmatrix} \Theta_{11,t-1} & \Theta_{12,t-1} \\ \Theta_{21,t-1} & \Theta_{22,t-1} \end{bmatrix} \\ = & \begin{bmatrix} (P_{11,t-1} + \Omega - \widetilde{P}_{12,t-1}\widetilde{P}_{22,t-1}^{-1}\widetilde{P}_{21,t-1})^{-1} & -(P_{11,t-1} + \Omega)^{-1}\widetilde{P}_{12,t-1}\Phi_{t-1} \\ -\Phi_{t-1}\widetilde{P}_{21,t-1}(P_{11,t-1} + \Omega)^{-1} & \Phi_{t-1} \end{bmatrix}, \end{aligned} \quad \text{(A.7)}$$

where $\Phi_{t-1} \equiv (\widetilde{P}_{22,t-1} - \widetilde{P}_{21,t-1}(P_{11,t-1} + \Omega)^{-1}\widetilde{P}_{12,t-1})^{-1}$.

Substituting the expressions of the (1,1) element $\Theta_{11,t-1}$ and (1,2) element $\Theta_{12,t-1}$ in equation (A.7) into equation (A.6), we obtain the following expression of G_t using the sub-matrices of $P_{t|t-1}$:

$$\begin{aligned} G_t &= \begin{bmatrix} G_t^X & \widetilde{G}_{12,t} \\ \widetilde{G}_{21,t} & \widetilde{G}_{22,t} \end{bmatrix} \\ &= \begin{bmatrix} I - \Omega(P_{11,t-1} + \Omega - \widetilde{P}_{12,t-1}\widetilde{P}_{22,t-1}^{-1}\widetilde{P}_{21,t-1})^{-1} & \Omega(P_{11,t-1} + \Omega)^{-1}\widetilde{P}_{12,t-1}\Phi_{t-1} \\ O & I \end{bmatrix}. \end{aligned} \quad \text{(A.8)}$$

(3) Proving that $G_t^X \neq O$

Suppose that $G_t^X = O$ holds. Then the (1,1) element of equation (A.8) becomes

$$I = \Omega(P_{11,t-1} + \Omega - \widetilde{P}_{12,t-1}\widetilde{P}_{22,t-1}^{-1}\widetilde{P}_{21,t-1})^{-1}.$$

Left-multiplying both sides by Ω^{-1} and taking the inverse matrices gives

$$P_{11,t-1} - \widetilde{P}_{12,t-1}\widetilde{P}_{22,t-1}^{-1}\widetilde{P}_{21,t-1} = O.$$

Applying the determinant formula of partitioned matrices yields

$$|P_{t|t-1}| = |\widetilde{P}_{22,t-1}| \cdot |P_{11,t-1} - \widetilde{P}_{12,t-1}\widetilde{P}_{22,t-1}^{-1}\widetilde{P}_{21,t-1}| = 0.$$

This implies that $P_{t|t-1}$ is singular, but $P_{t|t-1}$ must be non-singular since it is positive definite. This is a contradiction. Hence, we have $G_t^X \neq O$.

(4) Proving that $G_t^\pi \neq O$ and $G_t^Y \neq O$

Solving the (1,2) element in equation (A.8) for $\widetilde{P}_{12,t-1}$, we have

$$\begin{aligned}
\widetilde{P}_{12,t-1} &= [P_{12,t-1} \quad P_{13,t-1}] \\
&= (P_{11,t-1} + \Omega)\Omega^{-1}\widetilde{G}_{12,t}\Phi_{t-1}^{-1} \\
&= (P_{11,t-1} + \Omega)\Omega^{-1}[G_t^\pi \quad G_t^Y]\Phi_{t-1}^{-1}.
\end{aligned}$$

Suppose that either G_t^π or G_t^Y is a zero matrix. From the above equation, $P_{12,t-1} = O$ in the case of $G_t^\pi = O$, and $P_{13,t-1} = O$ in the case of $G_t^Y = O$. These contradict the fact that $P_{12,t-1} \neq O$ and $P_{13,t-1} \neq O$. Therefore, we must have $G_t^\pi \neq O$ and $G_t^Y \neq O$.

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Table 1: Test of FIRE for 1-year-ahead inflation expectations

(1) OLS regression by firm size and industry

	All	By firm size			By industry		
		Large	Medium-sized	Small	Manufacturing (Materials)	Manufacturing (Processing)	Non-manufacturing
β	3.28 **	4.28 **	3.14 *	2.99 **	3.17 **	2.85 **	3.16 *
	(1.41)	(1.93)	(1.47)	(1.27)	(1.37)	(1.16)	(1.50)
Adj. R^2	0.10	0.10	0.07	0.10	0.17	0.08	0.07
Obs.	13	13	13	13	13	13	13
$\frac{\beta}{1+\beta}$	0.77	0.81	0.76	0.75	0.76	0.74	0.76

Note: ** and * indicate the 5% and 10% significance level, respectively.
Standard errors are shown in parentheses (adjusted by Newey-West method for serial correlations).

(2) Panel-data regression

	Semi-aggregate panel data of 3 industries × 3 sizes
β	2.74 ***
	(0.10)
Adj. R^2	0.19
Obs.	117
$\frac{\beta}{1+\beta}$	0.73

Notes: 1. *** indicates the 1% significance level.
Standard error is shown in parentheses (adjusted by Newey-West method for serial correlations).
2. To take into account possible correlations among error terms in the cross-sectional dimension, the General FGLS method is employed.

Table 2: Answers for judgment items and assigned values

	+1	0	-1
Change in Input Prices	Rise	Unchanged	Fall
Change in Output Prices	Rise	Unchanged	Fall
Domestic Supply and Demand Conditions for Products and Services	Excess demand	Almost balanced	Excess supply
Employment Conditions	Insufficient employment	Adequate	Excess employment
Business Conditions	Favorable	Not so favorable	Unfavorable
Production Capacity	Insufficient capacity	Adequate	Excess capacity
Financial Position	Easy	Not so tight	Tight
Lending Attitude of Financial Institutions	Accommodative	Not so severe	Severe
Change in Interest Rate on Loans	Fall	Unchanged	Rise

Note: For *Change in Input Prices* , *Change in Output Prices* , and *Change in Interest Rate on Loans* , judgments are based on the change in conditions from three months prior to the time of the survey. For the other items, judgments are based on the conditions at the time of the survey.

Table 3: Results of dynamic panel-data regression

(1) 1-year-ahead inflation expectations

	All sizes		Large		Medium-sized		Small	
1-period lag	0.40	***	0.45	***	0.42	***	0.41	***
of inflation expectations	(0.04)		(0.08)		(0.07)		(0.05)	
2-period lag	0.10	***	0.14	**	0.09		0.12	***
of inflation expectations	(0.03)		(0.07)		(0.06)		(0.05)	
Input prices	0.04	***	0.02		0.02		0.06	***
	(0.01)		(0.02)		(0.02)		(0.02)	
Output prices	0.03	**	0.03		0.01		0.04	**
	(0.01)		(0.02)		(0.02)		(0.02)	
Domestic demand	0.05	***	0.00		0.03		0.05	***
	(0.01)		(0.03)		(0.02)		(0.02)	
Employment conditions	0.01		0.03		0.03	*	-0.00	
	(0.01)		(0.03)		(0.02)		(0.01)	
Obs.	221,563		38,602		61,705		121,256	
Number of firms	9,830		1,922		2,751		5,157	
Test of serial correlations	0.48		0.73		0.63		0.42	
Test of overidentification	0.25		0.33		0.27		0.37	

(2) 5-year-ahead inflation expectations

	All sizes		Large		Medium-sized		Small	
1-period lag	0.36	***	0.56	***	0.27		0.30	***
of inflation expectations	(0.07)		(0.13)		(0.23)		(0.09)	
2-period lag	0.09		0.24	**	-0.01		0.05	
of inflation expectations	(0.07)		(0.12)		(0.22)		(0.09)	
Input prices	0.03		-0.06		0.08	**	0.02	
	(0.02)		(0.04)		(0.04)		(0.03)	
Output prices	0.03		0.03		0.02		0.05	
	(0.02)		(0.04)		(0.04)		(0.03)	
Domestic demand	0.01		-0.06		-0.01		0.03	
	(0.02)		(0.04)		(0.04)		(0.02)	
Employment conditions	0.01		-0.00		0.02		0.01	
	(0.02)		(0.05)		(0.03)		(0.02)	
Obs.	144,517		20,826		40,375		83,316	
Number of firms	9,830		1,922		2,751		5,157	
Test of serial correlations	0.77		0.18		0.73		0.84	
Test of overidentification	0.84		0.73		0.12		0.42	

Notes: 1. *** , **, and * indicate the 1%, 5%, and 10% significance level, respectively. Standard errors are shown in parentheses.

2. *p* -values are reported for the tests of serial correlations and overidentification.

Table 4: Results of panel-data regression with additional judgment items

	1-year-ahead inflation expectations				5-year-ahead inflation expectations			
	(1)		(2)		(1)		(2)	
1-period lag	0.40	***	0.41	***	0.36	***	0.33	***
of inflation expectations	(0.04)		(0.04)		(0.07)		(0.09)	
2-period lag	0.10	***	0.12	***	0.09		0.06	
of inflation expectations	(0.03)		(0.04)		(0.07)		(0.08)	
Input prices	0.04	***	0.04	***	0.03		0.02	
	(0.01)		(0.01)		(0.02)		(0.02)	
Output prices	0.03	**	0.05	***	0.03		0.07	***
	(0.01)		(0.02)		(0.02)		(0.02)	
Domestic demand	0.05	***	0.05	***	0.01		0.01	
	(0.01)		(0.01)		(0.02)		(0.02)	
Employment conditions	0.01		0.02		0.01		0.00	
	(0.01)		(0.01)		(0.02)		(0.02)	
Business conditions			0.01				0.00	
			(0.01)				(0.01)	
Production capacity			-0.01				0.01	
			(0.02)				(0.02)	
Financial position			-0.01				0.02	
			(0.01)				(0.02)	
Lending attitude			0.00				0.01	
			(0.01)				(0.02)	
Interest rate on loans			-0.01				-0.02	
			(0.01)				(0.02)	
Obs.	221,563		201,188		144,517		132,415	
Number of firms	9,830		9,830		9,830		9,830	
Test of serial correlations	0.48		0.34		0.77		0.48	
Test of overidentification	0.25		0.11		0.84		0.25	

Notes: 1. *** and ** indicate the 1% and 5% significance level, respectively. Standard errors are shown in parentheses.
2. *p* -values are reported for the tests of serial correlations and overidentification.
3. The sample includes all firms. The column (1) in the table reproduces the results of the baseline case in Table 3.

Figure 1: Questionnaire for "Outlook for General Prices" in the *Tankan*

[Question]

What are your institution's expectations of the annual percent change in general prices (as measured by the consumer price index) for one year ahead, three years ahead, and five years ahead, respectively?
Please select the range nearest to your own expectation from the options below.

Note: Please choose one of the alternatives, excluding the effects of changes due to institutional factors such as the consumption tax.

[Options for answer]

1	around +6% or higher	(+5.5% or higher)
2	around +5%	(+4.5% ~ +5.4%)
3	around +4%	(+3.5% ~ +4.4%)
4	around +3%	(+2.5% ~ +3.4%)
5	around +2%	(+1.5% ~ +2.4%)
6	around +1%	(+0.5% ~ +1.4%)
7	around 0%	(-0.5% ~ +0.4%)
8	around -1%	(-1.5% ~ -0.6%)
9	around -2%	(-2.5% ~ -1.6%)
10	around -3% or lower	(-2.6% or lower)

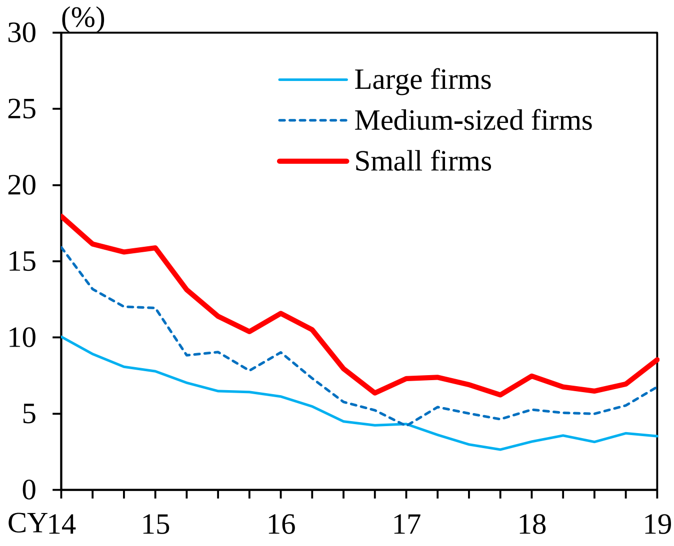
If you have no clear views on general prices, please select one of the three following reasons.

11	Uncertainty over the future outlook is high
12	Not really conscious of inflation fluctuations because they should not influence the strategy of the institution.
13	Other

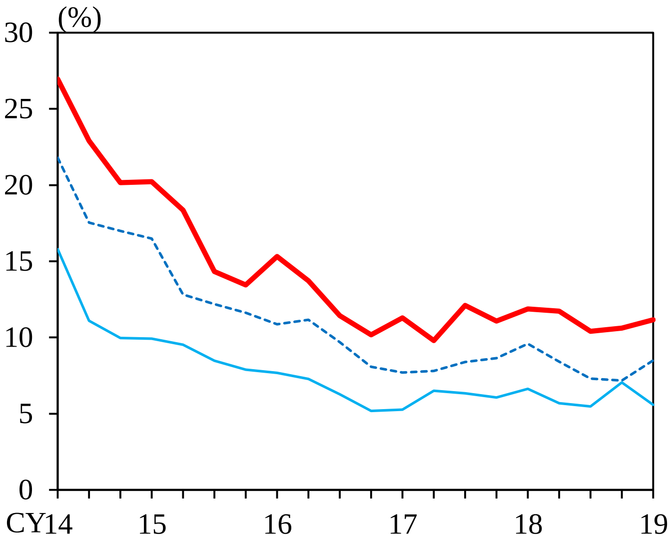
Figure 2: Stability of the firms' answers for inflation expectations

(1) Large revisions

(i) 1-year-ahead inflation expectations



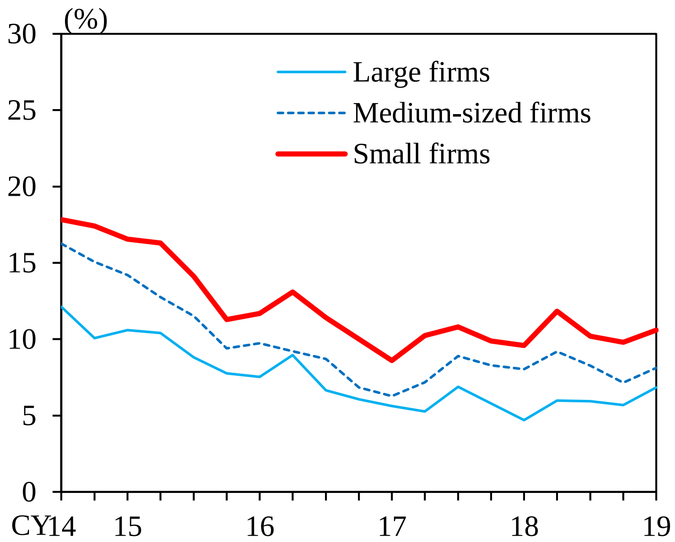
(ii) 5-year-ahead inflation expectations



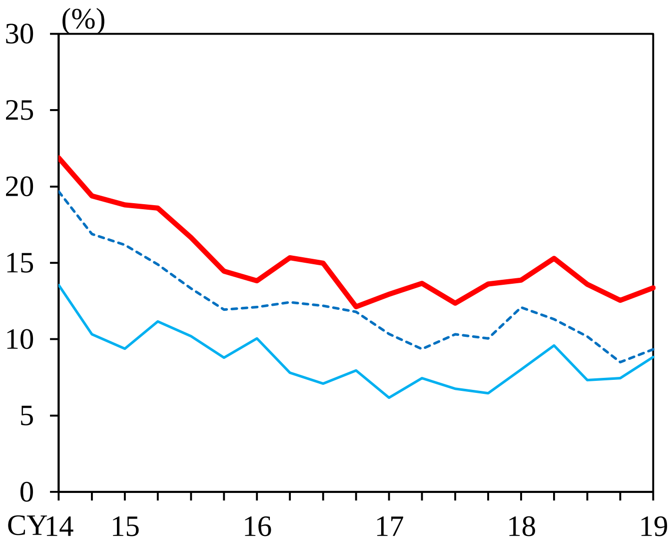
Note: The graphs show percentage share of the number of respondents revising expectations by more than 2% points upward or downward, among all firms choosing numeric options.

(2) Irregular revisions

(i) 1-year-ahead inflation expectations



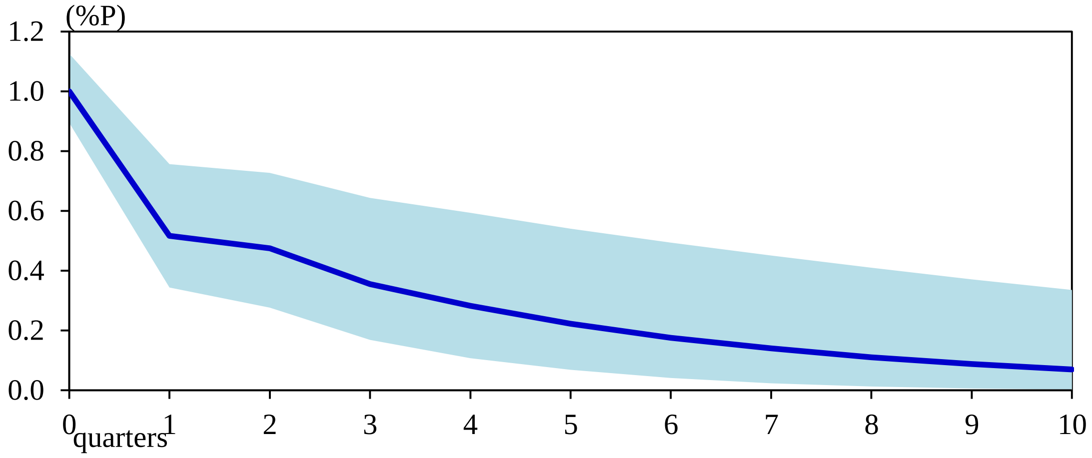
(ii) 5-year-ahead inflation expectations



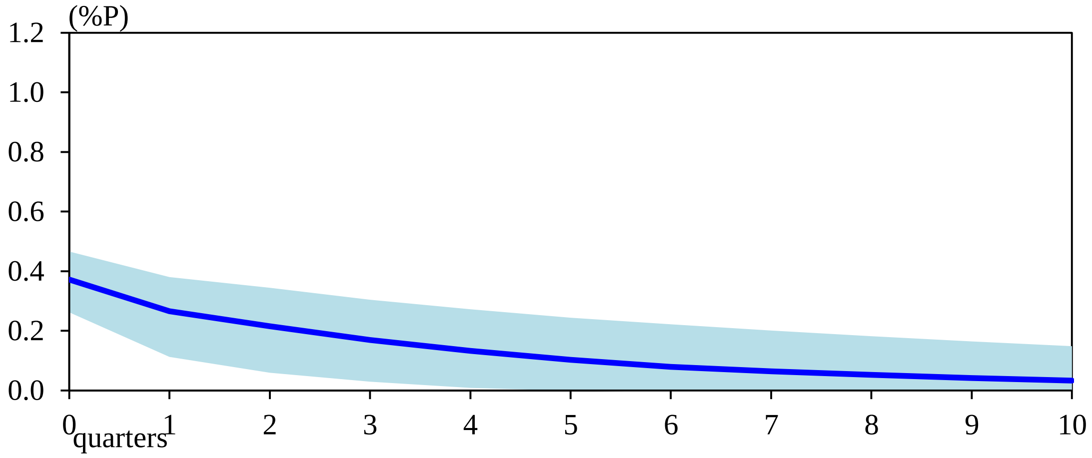
Note: The graphs show percentage share of the number of respondents revising expectations in the opposite direction to the previous survey, among all firms choosing numeric options.

Figure 3: Impulse responses to +1% shock in 5-year-ahead inflation expectations

(1) Impulse response of 5-year-ahead inflation expectations



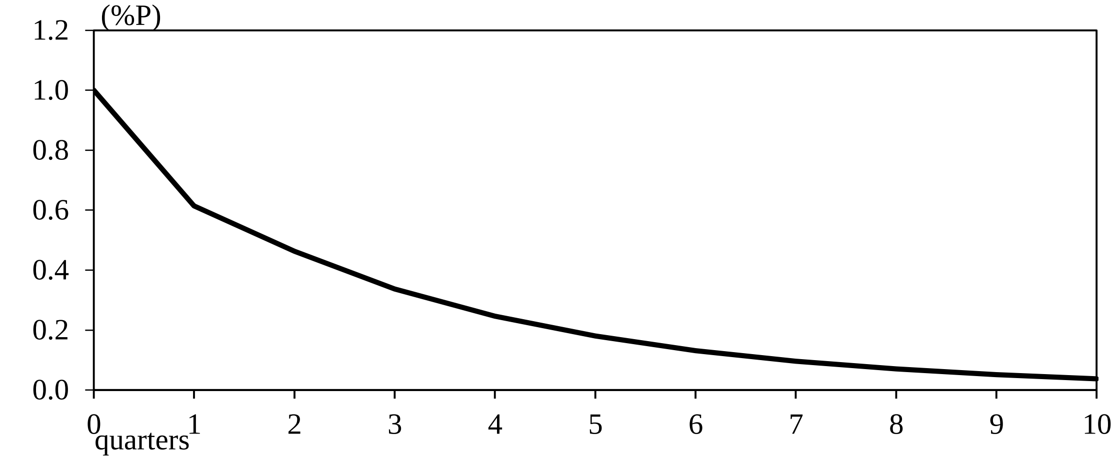
(2) Impulse response of 1-year-ahead inflation expectations



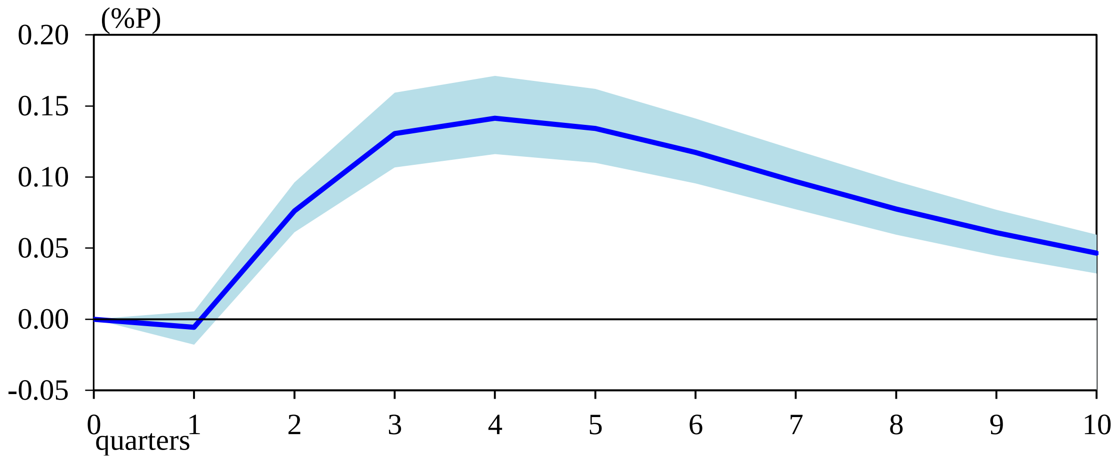
Note: Shaded areas indicate 5-95% confidence bands calculated via bootstrapping (cross-sectional resampling). The number of resampling is 100. Solid lines indicate the median.

Figure 4: Impulse responses of inflation expectations to +1% shock in actual inflation rate

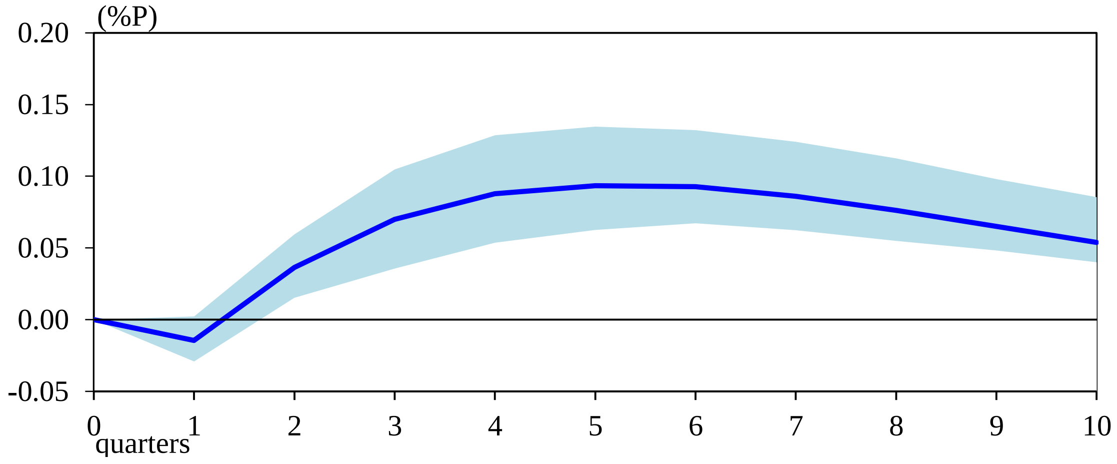
(1) Impulse response of inflation rate



(2) Impulse response of 1-year-ahead inflation expectations



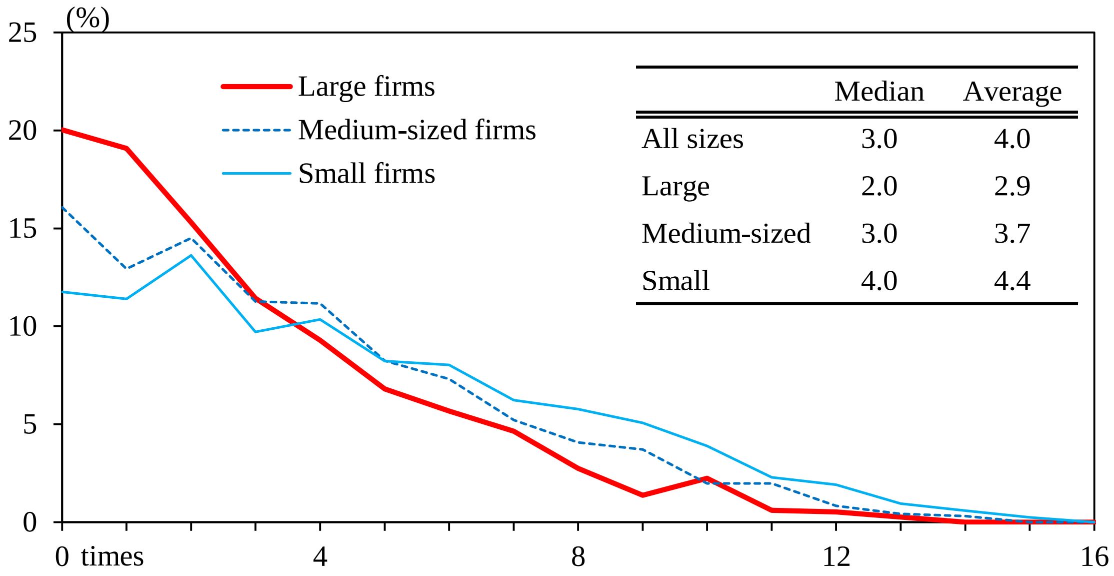
(3) Impulse response of 5-year-ahead inflation expectations



Note: Shaded areas indicate 5-95% confidence bands calculated via bootstrapping (cross-sectional resampling).
The number of resampling is 100. Solid lines indicate the median.

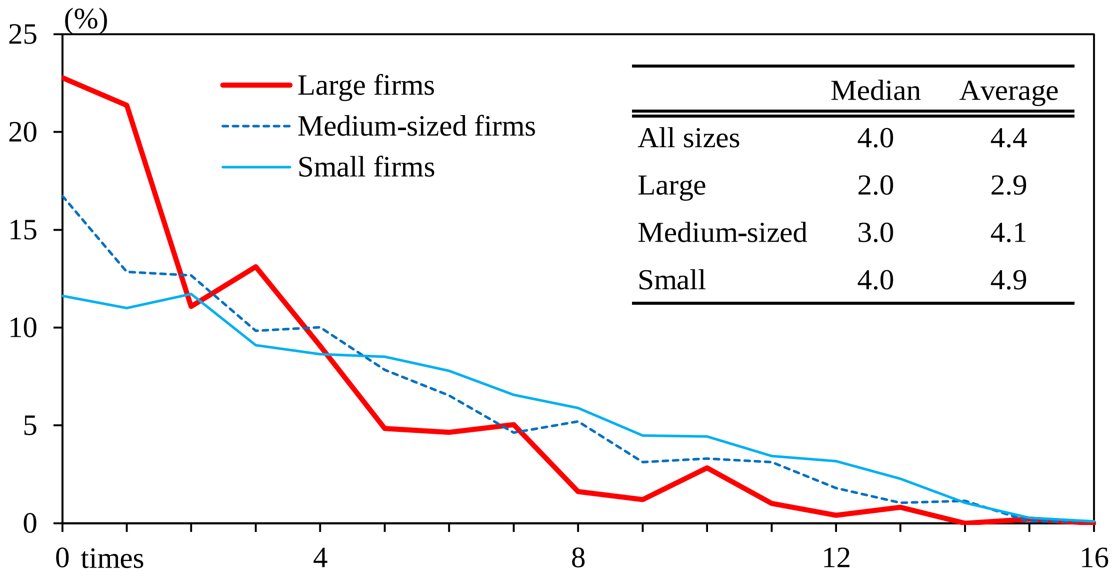
Figure 5: Frequency of revisions of inflation expectations

(1) 1-year-ahead inflation expectations



	Median	Average
All sizes	3.0	4.0
Large	2.0	2.9
Medium-sized	3.0	3.7
Small	4.0	4.4

(2) 5-year-ahead inflation expectations



	Median	Average
All sizes	4.0	4.4
Large	2.0	2.9
Medium-sized	3.0	4.1
Small	4.0	4.9

Notes: 1. The frequencies are calculated for firms that chose numeric options for all the rounds of the survey during the sample period.
2. The sample period is from 2015Q1 to 2019Q1 (the maximum number of revisions is 16).