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Household Inflation Expectation and Consumption
── Evidence from Japan* ──

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We study household inflation expectation and consumption decisions jointly, using the micro-level panel dataset based on household surveys in Japan when nominal interest rates stay at the effective lower bound. We find that a rise in household inflation expectation generally leads to a rise in current consumption relative to future. However, we find that this relation may not be robust in some situations. Specifically, changes in household inflation expectations along with the fluctuation in food and energy prices have a little impact on consumption, whereas changes in their inflation expectations due to other factors have a strong impact. Building a formal model and calibrate its parameters, we show that these results can be interpreted as the household's optimal behavior under imperfect information.
JEL Classification Codes: E50, E21, E61

1. Introduction

As short-term nominal interest rates declined in many countries, inflation expectation has drawn attention from policymakers. This is because a standard theory predicts that the central bank can still stimulate current consumption if it successfully raises households' inflation expectations, even though nominal interest rates hit the zero lower bound (Krugman 1998). This idea gives a foundation to many innovative monetary policies recently observed such as the forward guidance (Eggertsson and Woodford 2003)[1]. However, as we discuss momentarily, empirical evidence on the theoretical prediction is mixed.

The current paper provides new evidence on the issue with unique data. Specifically, we employ a panel dataset of Japanese households during the period of virtually zero lower bound, from 2010 to 2018. The data contain numerical information on households' inflation expectations, changes in expenditure, changes in the planned expenditure, and income expectations, with which various demographic factors can be controlled using individual level fixed effects in panel-data estimations.

In the baseline regression, we confirm a negative relationship between expected consumption growth and inflation expectation. In addition, we find interesting new results suggesting no significant effect of the changes in households' inflation expectations along with developments in recent food and energy prices on their inter-temporal consumption allocation. Meanwhile, changes in households' inflation expectations caused by other factors lead to a significant adjustment. In other words, the relationship between households' inflation expectations and consumption may not be perfectly stable across states, but it may be state dependent in the sense that the relationship is observed in certain situations but not in the other.

We interpret this result as household's optimal behavior under imperfect information. We show a canonical consumption-choice model having two types of goods. The first one is meant to capture characteristics of food- and energy-related products. Specifically, people are less willing to substitute its consumption across time, and its inflation dynamics are subject to relative price shocks. The other one is relatively easier to substitute across time, and its inflation dynamics are mainly determined by aggregate macroeconomic conditions.

Under this setting, we obtain the following results. If households observe the price hike in goods and services other than food and energy, they increase current consumption (and decrease future consumption) of these items through inter-temporal substitution channel because they expect future inflation in these items. By contrast, the price hike in food- and energy-related products does not increase households' inflation expectations about the other items, because they reasonably guess that sector-specific shocks most likely caused inflation in food- and energy-related products. Consequently, the households do not adjust consumption much, even though they update their inflation expectations somewhat positively. Predictions from a calibrated version of our model are broadly consistent with the empirical results.

The remainder of the paper is organized as follows. Section 2 discusses related literature and subsequently presents an empirical analysis on the relationship between households' inflation expectations and their inter-temporal consumption allocations at the zero lower bound. Section 3 develops the model of households' inter-temporal consumption allocations under imperfect information. Section 4 concludes.

Related literature. Our study is closely related to two strands of literature. The first one is a growing literature evaluating the link between households' inflation expectations and their consumption (spending) decisions (Coibion, Gorodnichenko, Kumar, and Pedemonte 2020). Assuming households' optimal behavior, one would expect a positive link between inflation expectation and current consumption, because higher inflation expectation means lower real interest rate, other things being equal. In the United States, Crump, Eusepi, Tambalotti, and Topa (2015) reported a positive correlation between households' inflation expectations and the growth of their consumption. Meanwhile, Burke and Ozdagli (2013) and Bachmann, Berg, and Sims (2015) found little evidence on the link between households' inflation expectations and their readiness to spend (or actual spending) on durables. In Europe and Japan, several studies have found significantly positive links between households' inflation expectations and their (intended or actual) spending on both durables and non-durables (Ichiue and Nishiguchi 2015; D'Acunto, Hoang, and Weber 2017; Duca, Kenny, and Reuter 2018; Vellekoop and Wiederholt 2017; Ichiue, Koga, Okuda, and Ozaki 2019; Dräger and Nghiem 2020). Our study contributes to this literature by reporting a new evidence suggesting that not finding a strong link between households' inflation expectations and their inter-temporal consumption allocations in some cases, because it may be state dependent, is not completely surprising.

Second, our study is related to the literature emphasizing the importance of heterogeneous expectations. Several papers have reported their important consequences to households' decisions (Bachmann *et al.*, 2015; Duca, Kenny, and Reuter 2018; Dräger and Nghiem, 2020). Jonung (1981), Bryan and Venkatu (2001), Souleles (2004), Blanchflower and MacCoille (2009), and Pfajfar and Santoro (2009) reported interesting regularities in expectation variations. For example, women tend to have high inflation expectations, both perceived and expected, and so do low education and low income groups. Similarly, inflation expectations among young and old respondents are higher than those of middle-age respondents. Researchers attempt to understand the reasons behind these regularities. Clark and Davig (2008), Coibion and Gorodnichneko (2015a,b), Wong (2015), and D'Acunto *et al*. (2019) argued that the gender differences in inflation expectations can be traced to differences in daily grocery shopping experiences[2]. Further, Ehrmann and Tzamourani (2012), Malmendier and Nagel (2016), Axelrod *et al.* (2018), and Diamond, Watanabe, and Watanabe (2020) stressed the importance of long-run inflation experience. Meanwhile, D'Acunto *et al*. (2019) argued the importance of cognitive ability in inflation expectations formations. We interpret heterogeneity in inflation expectation in our data considering these studies. Finally, we connect changes in inflation expectation and consumption, and interpret the empirical result in the context of imperfect information models (Carroll 2003, Pfajfar and Santoro 2013, Coibion and Gorodnichenko 2012, Abe and Ueno 2016)[3].

2. Empirical Analysis

2.1 Dataset

The Preference Parameters Study is provided by the Institute of Social and Economic Research at Osaka University[4]. The dataset is based on a longitudinal annual survey conducted annually from January to March. The first and last waves were conducted in 2003 and 2018, respectively. Note that a hiatus occurred in 2014 and 2015. We use the waves in the period of 2010 to 2018 for the analysis, which corresponds to the periods of the post-global financial crisis. The policy rate has been near zero, and the nominal yield curve is quite flat during these periods. This is an advantage because we can relatively safely assume that the nominal interest rate is expected to be invariant for the households. Under this assumption, changes in households' inflation expectations and changes in the real interest rate are identical.

The dataset covers about 4,000 households on average each year, and the response rate to each survey is more than 70 percent[5]. Survey households are chosen based on stratified two-stage random sampling using the "Basic Resident Registration" compiled by the Ministry of Internal Affairs and Communications.

For this study's purpose, asking the respondents to choose items representing numerical ranges for the one year ahead inflation expectations is useful. The question and choices are as follows.

- (Question) *By what percentage do you expect consumer prices will change in 2013 compared with the previous year?*

- (Choices for answers) *(0) Decrease by at least 4.5%; (1) Decrease by at least 3.5% but less than 4.5%; (2) Decrease by at least 2.5% but less than 3.5%; (3) Decrease by at least 1.5% but less than 2.5%; (4) Decrease by at least 0.5% but less than 1.5%; (5) Change by less than 0.5% in either direction; (6) Increase by at least 0.5% but less than 1.5%; (7) Increase by at least 1.5% but less than 2.5%; (8) Increase by at least 2.5% but less than 3.5%; (9) Increase by at least 3.5% but less than 4.5%; (10) Increase by at least 4.5%.*

The survey also asks about the change in respondents' expenditure plans. The following are the question-and-answer choices regarding the expected changes in their expenditure plans:

- (Question) *In 2013, what will be the approximate percentage change in your family's total annual expenditures compared with 2012?*

- (Choices for answers) *(0) Decrease by at* *least 9%; (1) Decrease by at least 7% but less than 9%; (2)Decrease by at least 5% but less than 7%; (3) Decrease by at least 3% but less than 5%; (4)Decrease by at least 1% but less than 3%; (5) Change by less than 1% in either direction; (6) Increase by at least 1% but less than 3%; (7)Increase by at least 3% but less than 5%; (8) Increase by at least 5% but less than 7%; (9) Increase by at least 7% but less than 9%; (10) Increase by at least 9%.*

In the following, we use the midpoint of the numerical range of each response category[6)].

The survey also provides information on households' detailed expenditures, incomes, and demographic characteristics (e.g., gender, age, employment status, and education). Table 1 describes the summary statistics of the survey.

2.2 Developments in inflation expectations

We briefly refer to the developments in households' inflation expectations in the Preference Parameter Survey. Panel (a) of Figure 1 plots the aggregate inflation expectations (mean and median) across households and consumer price inflation. The households' inflation expectations comove with the recent consumer price inflation at the aggregate level. The households' inflation expectations have increased twice: during the recovery from the global financial crisis from 2010 to 2011, and after the introduction of the two percent inflation target and aggressive monetary easing in 2013. Panel (b) shows the distribution of households' inflation expectations in each wave, which indicates heterogeneity of households' inflation expectations in Japan at the disaggregate level[7)].

The developments in households' inflation expectations by demographic groups are presented in Table 2. Columns (1), (2), and (3) show the developments in the averages of the households' inflation expectations by gender, education level, and income level, respectively. Consistent with the existing literature, women, low education, and low income groups present higher inflation expectations[8)]. In what follows, we associate some of these variations to their recent shopping experiences. In addition, column (4) of Table 2 shows the inflation expectations by age (cohort), confirming cohort effects. Specifically, older household members who experienced high inflation periods (i.e., oil shocks in the 1970s) hold higher inflation expectations. This finding is consistent with the result by Diamond, Watanabe, and Watanabe (2020), who examined the cohort effects in inflation expectations formation with a different dataset of Japanese households' inflation expectations. We control these cohort effects by including the dummy variable for the elderly in our regression analysis because they are less likely to be explained by recent shopping experiences.

2.3 Developments in consumption growth

Next, we show the developments in households' plan for the growth rate of nominal consumption over the next year. Table 3 compares the averages of the growth rates of the expected and actual nominal consumption. We find the comovement between the expected and actual nominal consumption, implying the link between the individuals' consumption plans in the survey and actual consumption. Table 4 decomposes the data. The first table reports the averages of the growth rate of expected nominal consumption across households in each generation. For example, the first column shows the averages across elderly households who were born between 1930 and 1949, and the last column shows the averages across young households who were born between 1980 and

Table 1. Summary Statistics.

Questionnaire	Obs.	Mean	Stdev	Min	Max
Expected inflation rate over the next year Category [−5, −4, −3, −2, −1, 0, 1, 2, 3, 4, 5] (year-on-year change, %)	24,281	0.97	1.45	−5	5
Expected nominal expenditure changes over the next year Category [−10, −8, −6, −4, −2, 0, 2, 4, 6, 8, 10] (year-on-year change, %)	24,498	1.04	4.42	−10	10
Expected nominal income changes over the next year Category [−10, −8, −6, −4, −2, 0, 2, 4, 6, 8, 10] (year-on-year change, %)	23,213	−0.87	3.84	−10	10
Expected Japanese nominal average wage changes over the next year Category [−5, −4, −3, −2, −1, 0, 1, 2, 3, 4, 5] (year-on-year change, %)	3,556	0.33	1.16	−5	5
Changes in nominal expenditure from one year ago Category [−10, −8, −6, −4, −2, 0, 2, 4, 6, 8, 10] (year-on-year change, %)	24,344	1.41	4.6	−10	10
Changes in nominal income from one year ago Category [−10, −8, −6, −4, −2, 0, 2, 4, 6, 8, 10] (year-on-year change, %)	24,266	−0.99	4.13	−10	10
Household income before tax and with bonuses Category [0.5, 1.5, 3.0, 5.0, 7.0, 9.0, 11, 13, 15, 17, 19, 21] (Million yen)	23,373	6.12	3.82	0.5	21
Number of household members	25,764	3.38	1.44	1	13
I am so occupied with my daily life that I cannot save much money Category [1, 2, 3, 4, 5] (1: particularly true – 5: doesn't hold true at all)	25,892	2.86	1.18	1	5
Financial assets Category [1.25, 3.75, 6.25, 8.75, 12.5, 17.5, 25, 40, 75, 110] (Million yen)	21,876	13.94	19.17	1.25	110
Gender Category [1, 2] (1: Male, 2: Female)	26,007	1.54	0.5	1	2
Birth year Category [1, 2, 3, 4, 5] (1: 1980–1989, 2: 1970–1979, 3: 1960–1969, 4: 1950–1959, 5: 1930–49)	18,718	3.54	1.24	1	5
Education Category [1, 2] (1: Graduated from College or lower, 2: Graduated from University or higher)	10,155	1.25	0.43	1	2

Note) The figures are based on samples from 2010 to 2018 (excluding 2014 and 2015 due to a hiatus). Age and educational attainment were consolidated into the five and three groups shown here by the authors. The survey collected responses on education by 2011. We extrapolate them to apply for regression by using the response of the latest response.

Figure 1. Household's Inflation Expectation.

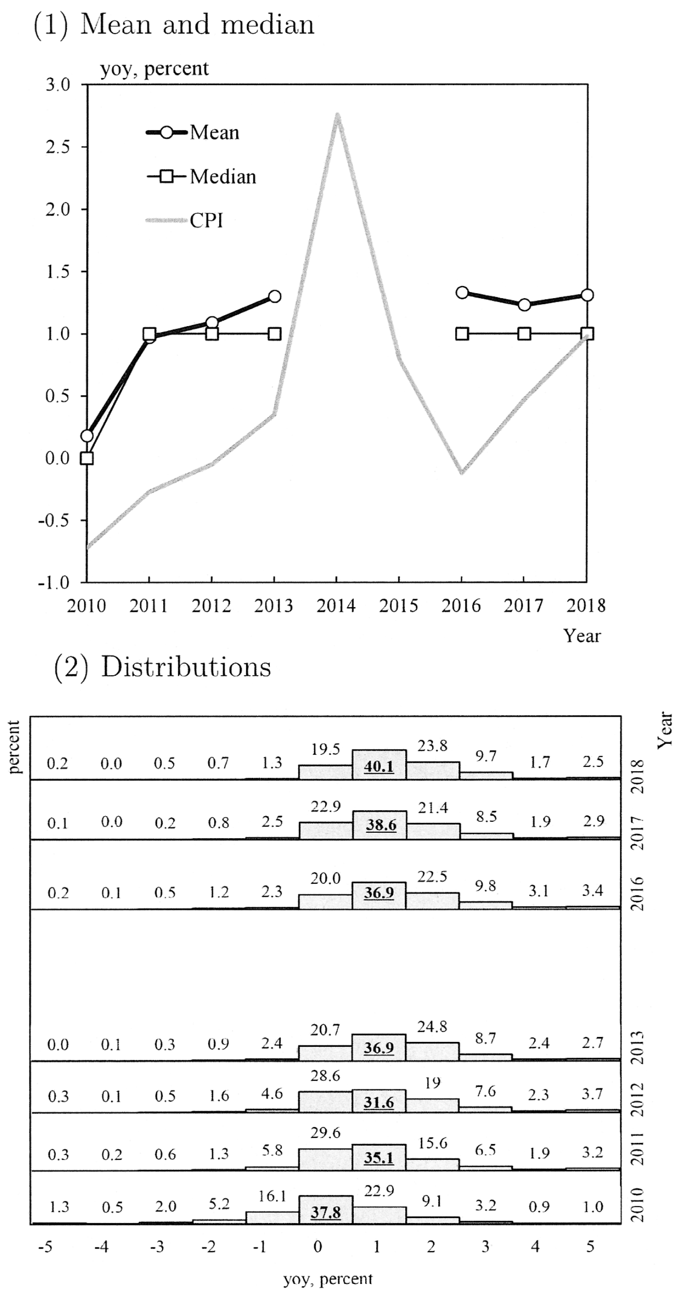

Table 2. Household's Inflation Expectations (over the next year, percent).

Year	(1) Gender Male	Female	(2) Education University (or higher)	College (or lower)	(3) Annual household income $X<4$ (million yen)	$4\leq X<8$	$8\leq X$
2010	−0.0	0.4	−0.1	0.3	0.2	0.2	0.1
2011	0.9	1.0	0.8	1.0	1.1	1.0	0.8
2012	1.0	1.1	0.9	1.2	1.2	1.1	1.0
2013	1.3	1.3	1.2	1.3	1.4	1.3	1.2
2014	—	—	—	—	—	—	—
2015	—	—	—	—	—	—	—
2016	1.3	1.4	1.3	1.3	1.4	1.4	1.2
2017	1.2	1.3	1.1	1.3	1.3	1.2	1.1
2018	1.3	1.3	1.3	1.3	1.4	1.3	1.3

Year	(4) Birth year 1930 to 1949	1950 to 1959	1960 to 1969	1970 to 1979	1980 to 1989
2010	0.2	0.1	0.2	0.1	0.2
2011	1.1	1.0	0.9	0.8	0.7
2012	1.3	1.1	1.0	0.9	0.8
2013	1.5	1.4	1.2	1.0	1.2
2014	—	—	—	—	—
2015	—	—	—	—	—
2016	1.6	1.4	1.2	1.1	1.2
2017	1.5	1.3	1.0	1.1	1.0
2018	1.5	1.3	1.2	1.1	1.3

Note) College includes associate degree (2 year). Annual household income is before taxes and with bonus basis.

Table 3. Household's Planned and Actual Consumption (annual change, percent).

Year	Plan	Actual
2010	0.4	1.7
2011	0.8	1.4
2012	1.2	1.5
2013	—	—
2014	—	—
2015	—	—
2016	1.6	1.8
2017	1.5	1.7

Note) The figures are the averages of the samples that answer to both planned and actual consumption and keep the number of people per household unchanged between the waves.

1989. The entries show the tendency for elderly households (vs. younger households) to report lower growth rates. The second table reports the averages of the growth rate of expected nominal consumption across households in each income bracket. For instance, the first column shows the averages across relatively low income households whose yearly income is less than 4 million yen, and the last column shows the averages across relatively high-income households whose yearly income is more than 8 million yen. The entries show a higher level of growth rates among higher-income households than lower-income ones. These results imply that the demographic characteristics of the households affect their consumption behavior. We control the effects by including individual level fixed effects in our regression analysis of the Euler equation[9].

2.4 Inflation Expectations Formation

Using the dataset presented above, we estimate the impact of households' recent shopping experiences on their inflation expectations formation. We begin our analysis by examining the link between households' recent inflation experience at the aggregate level. We denote household i's one year ahead inflation expectations reported in period t by $\pi_t^e(i)$. We then estimate the following

Table 4. Household's Planned Consumption by Demographic Groups (annual change, percent).

(1) Birth year

Year	1930 to 1949	1950 to 1959	1960 to 1969	1970 to 1979	1980 to 1989
2010	0.1	−0.1	1.1	0.6	0.3
2011	0.4	0.3	1.4	1.5	0.5
2012	1.0	0.6	1.6	1.4	0.5
2013	1.4	1.2	1.8	1.4	0.9
2014	—	—	—	—	—
2015	—	—	—	—	—
2016	1.6	1.1	1.3	2.1	1.4
2017	1.6	1.1	1.3	1.9	0.8
2018	1.6	1.5	1.2	1.8	2.1

(2) Annual household income (million yen)

Year	$X<4$	$4\leq X<8$	$8\leq X$
2010	0.1	0.7	1.0
2011	1.1	1.9	2.1
2012	1.0	1.5	1.7
2013	1.3	1.8	1.8
2014	—	—	—
2015	—	—	—
2016	1.5	2.2	2.3
2017	1.2	1.9	2.2
2018	1.3	1.8	2.0

Note) The figures are the averages of the samples that answer to both planned and actual consumption and keep the number of people per household unchanged between the waves.

empirical equation,

$$\pi_t^e(i) = \alpha + \beta\pi_{t-1}^{CPI} + \gamma X_t(i) + \varepsilon_t(i), \quad (1)$$

where α is a constant term, π_{t-1}^{CPI} is the year-on-year changes in consumer price index (overall) as a proxy for the household's recent inflation experience at the aggregate level, $X_t(i)$ is the dummy variable for the elderly, and $\varepsilon_t(i)$ is the error term. Column (1) of Table 5 lists the estimates for the regression coefficients of the equation (1). It shows a positive and statistically significant $\hat{\beta}$, which is the estimate of the coefficient for the households' recent inflation experience at the aggregate level (π_{t-1}^{CPI}). Column (2) shows an estimation result when the regional consumer price index corresponding the household's prefecture of residence instead of the index of the whole of Japan is employed, confirming that $\hat{\beta}$ is positive and statistically significant. These results are consistent with the view that Japanese households form their inflation expectations based on their recent shopping experiences[10].

Next, we investigate the households' inflation expectations formation using the year-on-year changes in the prices of food (π_{t-1}^{food}) and energy (π_{t-1}^{energy}) because they are closely linked to households' daily shopping experience. The inflation rates of food and energy are calculated based on the regional consumer price index corresponding to the household's prefecture of residence. To account for the heterogeneous consumption basket across households, we calculate the Engel's coefficient ($s_t^{food}(i)$) based on the information on the households' expenditures to food and their total expenditures from the survey. We capture the heterogeneity by including the cross term between the year-on-year changes in the prices of food (π_{t-1}^{food}) and the Engel's coefficient ($s_t^{food}(i)$). The control variable is the same as that in

Table 5. Estimation Results for the Link Between Household's Inflation Expectations Formation and Inflation Experience at the Aggregate Level.

Dependent variable: Expected inflation rate over the next year.

	(1)	(2)
Consumer price inflation	0.49***	
(year-on-year changes)	(0.08)	
Regional consumer price inflation		0.31***
(year-on-year changes)		(0.06)
Intercept	0.94***	0.90***
	(0.05)	(0.03)
Birth year	0.22***	0.23***
(dummy: 1930–1959)	(0.02)	(0.02)
Estimation period	2010–2018	2010–2018
Adjusted R-squared	0.16	0.11
Observations	24281	24281
Number of households	5262	5262
Individual fixed effect	No	No
Time fixed effect	No	No

Note) Robust standard errors in parentheses. *** indicates significance at the 1% level. The coefficients are estimated using weighted least squares (WLS). For birth year dummy, the baseline category is 1960–1989.

Table 6. Estimation Results for Household's Inflation Expectations Formation.

Dependent variable: Expected inflation rate over the next year.

	(1)	(2)	(3)	(4)
Food price inflation	0.06***	0.04***		0.21***
(year-on-year changes)	(0.01)	(0.01)		(0.01)
× Engel's coefficient		0.01**		0.01***
		(0.00)		(0.00)
Energy price inflation			0.02***	0.05***
(year-on-year changes)			(0.01)	(0.00)
Intercept	0.85***	0.91***	0.87***	0.88***
	(0.02)	(0.01)	(0.04)	(0.01)
Birth year	0.17***	0.11***	0.16***	0.17***
(dummy: 1930–1959)	(0.02)	(0.02)	(0.03)	(0.02)
Estimation period	2010–2018	2010–2018	2010–2018	2010–2018
Adjusted R-squared	0.03	0.02	0.05	0.56
Observations	24281	18532	24281	18532
Number of households	5262	4750	5262	4750
Individual fixed effect	No	No	No	No
Time fixed effect	No	No	No	No

Note) Robust standard errors in parentheses. *** and ** denote significance at the 1% and 5% level, respectively. The coefficients are estimated using WLS. Price index is the regional consumer price index corresponding to the household's prefecture of residence. For birth year dummy, the baseline category is 1960–1989.

equation (1), that is, the dummy variable for the elderly ($X_t(i)$). The empirical specification is given as

$$\pi_t^e(i) = \alpha + \beta_1 \pi_{t-1}^{food} + \beta_2 s_t^{food}(i) \pi_{t-1}^{food} + \beta_3 \pi_{t-1}^{energy} + \gamma X_t(i) + \varepsilon_t(i). \quad (2)$$

Table 6 shows the estimation results for these regression coefficients. In particular, column (4) shows the estimation result of the parameters $\{\beta_1, \beta_2, \beta_3\}$ in the full model by equation (2). Columns (1), (2), and (3) show the estimation results of the parameters in the simpler models. In particular, column (1) shows the estimate of β_1 under the assumption of $\beta_2 = \beta_3 = 0$. Column (2) shows the estimates of $\{\beta_1, \beta_2\}$ under the assumption of

Table 7. Robustness Check for the Link Between Household's Inflation Expectations Formation and Inflation Experience at the Aggregate Level with Additional Control Variables.

Dependent variable: Expected inflation rate over the next year.

	(1)	(2)
Consumer price inflation	0.54***	
(year-on-year changes)	(0.20)	
Regional consumer price inflation		0.33***
(year-on-year changes)		(0.04)
Intercept	0.90***	0.85***
	(0.03)	(0.03)
Birth year	0.20***	0.21***
(dummy: 1930-1959)	(0.04)	(0.03)
Female	0.11***	0.09***
(dummy)	(0.02)	(0.02)
College	0.11***	0.12***
(or lower, dummy)	(0.03)	(0.02)
Low income	0.01	0.01**
(less 4 million yen, dummy)	(0.01)	(0.006)
Estimation period	2010-2018	2010-2018
Adjusted R-squared	0.27	0.27
Observations	8060	8060
Number of households	3063	3063
Individual fixed effect	No	No
Time fixed effect	No	No

Note) Robust standard errors in parentheses. *** and ** indicate significance at the 1% and 5% level, respectively. The coefficients are estimated using WLS. For birth year dummy, the baseline category is 1960-1989.

$\beta_3=0$; this implies that only the food price affects inflation expectations. Column (3) shows the estimate of β_3 under the assumption of $\beta_1=\beta_2=0$, which means that only the energy price affects inflation expectations. We observe the restrictive models, that is, those including only the developments in food prices or energy prices (columns (1)-(3)), exhibit a low level of adjusted R-squared (0.02-0.05). By contrast, the full model that includes both prices (column (4)) generates a high level of adjusted R-squared (0.56). These results imply that households form their inflation expectations based on the recent price changes in both the food- and energy-related products.

Table 7 presents the regression result for robustness check. We add dummies for women, low education, and low income group. All the coefficients for these factors are statistically significant in the direction implied by the earlier discussion. We could include contributions of these additional factors for the following analysis; however, it causes an unstable estimation result due to the limited number of samples compared with the number of explanatory variables. Therefore, following Diamond, Watanabe, and Watanabe (2020), we only include the control variable of the age cohort effect and leave the effects of the other control variables as the other factors.

Using the estimated full model (equation (2)), we show in Table 8 the decomposition of the developments in average inflation expectations into food price factors (averages of $\beta_1\pi_{t-1}^{food}+\beta_2 s_t^{food}(i)\pi_{t-1}^{food}$ across all samples), energy price factors (averages of $\beta_3\pi_{t-1}^{energy}$ across all samples), constant (averages of $\alpha+\gamma X_t(i)$ across all samples), and residuals (averages of $\varepsilon_t(i)$ across all samples). The first, second, and third col-

Table 8. Decomposition of the Developments in Average Inflation Expectations.

	2010–2012 average	2013	2016–2018 average
Expected inflation rate	0.76	1.33	1.33
Food price factors	−0.06	0.00	0.39
Energy price factors	−0.05	0.21	−0.21
Intercept	0.98	0.98	0.98
Residuals	−0.11	0.14	0.16

Note) The expected inflation rate is over the next year. Food price factors include the cross term with Engel's coefficient. Intercept includes the dummy variable for the elderly (whose birth year is during 1930–1959).

umns indicate the averages of the contribution of each factor in 2010–2012, in 2013, and in 2016–2018, respectively. The figures are computed by averaging each contribution of each sample by year. The contribution of intercept includes the effect of the birth dummy. Table 8 indicates negative food and energy price factors in 2010–2012. Meanwhile, food and energy price factors gave inflationary and deflationary pressure, respectively, in 2016–2018. These results imply that both food and energy price factors play unique roles in shaping households' inflation expectations. We thus confirm the importance of considering changes in both food and energy prices for the analysis on households' inflation expectations formation, justifying the specification by equation (2). Interestingly, the unexplained component in changes in households' average inflation expectations has been exhibiting positive contributions since 2013. Perhaps the introduction of the two percent inflation target, adopted by the Bank of Japan, contributed to it.

2. 5 Euler Equation

We next examine the link between households' inflation expectations and consumption plans (the growth rate of consumption). Following Ichiue and Nishiguchi (2015), we convert nominal values into real values because respondents answer their consumption plans in nominal values. Specifically, we construct the variable for the expected growth of real consumption by subtracting the inflation expectations from the expected growth of nominal consumption. Here, we assume that a consumption basket of the consumption plan for each household is the same as in the inflation expectations. We denote the variable for household i in period t by $y_t^e(i)$.

We first evaluate whether households' adjustment process of their consumption plans agrees with the standard theory and existing studies on the empirical validity of the Euler equations for Japanese households (Ichiue and Nishiguchi 2015; Ichiue, Koga, Okuda, and Ozaki 2019). In particular, we estimate the following Euler equation,

$$\Delta y_{t+1|t}^e(i) = a(i) + b\pi_t^e(i) + cY_t(i)\pi_t^e(i) + \varepsilon_t(i), \quad (3)$$

where $a(i)$ is the individual level fixed effect, $\pi_t^e(i)$ is the inflation expectations, $Y_t(i)$ is the control variable, and $\varepsilon_t(i)$ is the error term[11]. The policy rate in Japan has been near zero, and the nominal yield curve is quite flat during the sample period. Therefore, we reasonably assume that the nominal interest rate is invariant for the households. We input a variety of control variables into $Y_t(i)$ to control the effects of demographic characteristics and borrowing constraint on the sensitivity of the households' intertemporal consumption allocations to changes in their underlying inflation expectations[12]. Note that because the dependent variable is the growth rate of real consumption from today, the income effect is expected to be

Table 9. Estimation Results for the Euler Equation.

Dependent variable: Expected growth of real consumption over the next year.

	(1)	(2)	(3)	(4)	(5)
Inflation expectations	−0.28***	−0.32***	−0.22***	−0.23***	−0.31***
over the next year	(0.03)	(0.05)	(0.02)	(0.03)	(0.03)
× Birth year		0.07			
(dummy: 1930–1959)		(0.05)			
× Male			−0.12***		
(dummy)			(0.04)		
× University graduate				−0.21***	
(or higher, dummy)				(0.03)	
× Little saving					0.05
(dummy)					(0.07)
Intercept	0.35***	0.35***	0.34***	0.34***	0.35***
	(0.07)	(0.07)	(0.07)	(0.07)	(0.07)
Estimation period	2010–2018	2010–2018	2010–2018	2010–2018	2010–2018
R-squared	0.32	0.32	0.32	0.32	0.32
Observations	23991	23991	23991	23965	23991
Number of households	5233	5233	5233	5226	5233
Individual fixed effect	Yes	Yes	Yes	Yes	Yes
Time fixed effect	No	No	No	No	No

Note) Robust standard errors in parentheses. *** denotes significance at the 1% level. The coefficients are estimated using WLS. For birth year dummy, the baseline category is 1960–1989. Little saving refers to the answer " I am so occupied with my daily life that I cannot save much money."

silent about the changes in the dependent variable[13].

Table 9 shows the estimation results. The table has five columns, and in each column, we employ different variables into $Y_t(i)$. Some interaction terms between households' inflation expectations $(\pi_t^e(i))$ and the control variable $(Y_t(i))$, that is, some elements of c in equation (3), are significant. Important for us, in all columns the coefficients for households' inflation expectations (b) are negative and statistically significant, which are consistent with the Euler equation in standard economic theory and existing studies on the empirical validity of the Euler equations for Japanese households (Ichiue and Nishiguchi 2015; Ichiue, Koga, Okuda, and Ozaki 2019).

We then examine our hypothesis that the link between households' inflation expectations and their inter-temporal consumption allocations could be state dependent. Our strategy is to decompose individual's inflation expectations $\pi_t^e(i)$ into the components in equation (2). Namely, each household's inflation expectations are disassembled to (i) the contribution of the recent changes in food price $(\hat{\beta}_1\pi_{t-1}^{food}+\hat{\beta}_2 s_t^{food}(i)\pi_{t-1}^{food})$, (ii) the contribution of the recent changes in energy price $(\hat{\beta}_3\pi_{t-1}^{energy})$, and (iii) the sum of the contribution of other variables $(\hat{\varepsilon}_t(i))$ where $(\hat{\beta}_1, \hat{\beta}_2, \hat{\beta}_3)$ are the estimates in Table 6 and $(\pi_{t-1}^{food}, s_t^{food}(i), \pi_{t-1}^{energy}, \hat{\varepsilon}_t(i))$ are the household i's variables. We call the contributions (i), (ii), and (iii) as "food price factors", " energy price factors", and "other factors", respectively. We then estimate the following empirical equation:

$$
\begin{aligned}
\Delta y_{t+1|t}^e(i) &= a(i) + b_1\overbrace{[\hat{\beta}_1\pi_{t-1}^{food}+\hat{\beta}_2 s_t^{food}(i)\pi_{t-1}^{food}]}^{\text{food price factors}} \\
&\quad + b_2 \overbrace{\hat{\beta}_3\pi_{t-1}^{energy}}^{\text{energy price factors}} + b_3 \overbrace{\hat{\varepsilon}_t(i)}^{\text{other factors}} \\
&\quad + c_1 Y_t(i)[\hat{\beta}_1\pi_{t-1}^{food}+\hat{\beta}_2 s_t^{food}(i)\pi_{t-1}^{food}] \\
&\quad + c_2 Y_t(i)\hat{\beta}_3\pi_{t-1}^{energy} \\
&\quad + c_3 Y_t(i)\hat{\varepsilon}_t(i) + \varepsilon_t(i), \qquad (4)
\end{aligned}
$$

where $a(i)$ is the individual level fixed effect, b_1 is the coefficient for food price factors, b_2 is

Table 10. Estimation Results for the Euler Equation: The Role of Inflation Experience.

Dependent variable: Expected growth of real consumption over the next year.

	(1)	(2)	(3)	(4)	(5)
Food price factors	0.04	−0.34***	−0.12	0.16	0.14
	(0.16)	(0.08)	(0.17)	(0.16)	(0.21)
× Birth year		0.69**			
(dummy: 1930–1959)		(0.29)			
× Male			0.33		
(dummy)			(0.21)		
× University graduate				−0.37**	
(or higher, dummy)				(0.15)	
× Little saving					−0.10
(dummy)					(0.19)
Energy price factors	−0.12	−0.21***	−0.09	0.00	−0.16
	(0.11)	(0.06)	(0.14)	(0.11)	(0.16)
× Birth year		0.16			
(dummy: 1930–1959)		(0.24)			
× Male			−0.05		
(dummy)			(0.10)		
× University graduate				−0.40***	
(or higher, dummy)				(0.14)	
× Little saving					0.08
(dummy)					(0.19)
Other factors	−0.32***	−0.36***	−0.25***	−0.27***	−0.37***
	(0.03)	(0.05)	(0.02)	(0.03)	(0.03)
× Birth year		0.06			
(dummy: 1930–1959)		(0.07)			
× Male			−0.13***		
(dummy)			(0.04)		
× University graduate				−0.21***	
(or higher, dummy)				(0.05)	
× Little saving					0.07
(dummy)					(0.07)
Intercept	0.09	0.09	0.08	0.08	0.08
	(0.06)	(0.06)	(0.06)	(0.06)	(0.06)
Estimation period	2010–2018	2010–2018	2010–2018	2010–2018	2010–2018
R-squared	0.35	0.35	0.35	0.35	0.36
Observations	18490	18490	18490	18480	18303
Number of households	4744	4744	4744	4741	4734
Individual fixed effect	Yes	Yes	Yes	Yes	Yes
Time fixed effect	No	No	No	No	No

Note) Robust standard errors in parentheses. *** and ** denote significance at the 1% and 5% level, respectively. The coefficients are estimated using WLS. For birth year dummy, the baseline category is 1960–1989. Little saving refers to the answer "I am so occupied with my daily life that I cannot save much money."

the coefficient for energy price factors, and b_3 is the coefficient for other factors[14].

Table 10 shows the estimation results of (4). We find statistically insignificant coefficients for food price factors $(\hat{\beta}_1 \pi_{t-1}^{food} + \hat{\beta}_2 s_t^{food}(i) \pi_{t-1}^{food})$ and for energy price factors $(\hat{\beta}_3 \pi_{t-1}^{energy})$, but negative and statistically significant coefficients for other factors $(\hat{\varepsilon}_t(i))$. This suggests little effects of the changes in their inflation expectations driven by recent changes in food and energy prices on underlying consumption decisions whereas have significant effects of the changes in their inflation expectations driven by other factors. These results imply the state-dependence of the link between households' inflation expectations and their inter-temporal consumption allocations.

We also examine whether the estimation results on the Euler equation in Table 10 holds in actual consumption. We regress the difference between the actual growth rate of real consumption and the actual growth rate of real income on food price factors, energy price factors, and other factors. The growth rate of actual nominal consumption depends on the price changes between the periods; therefore, we also include the inflation rates of food, energy, and other prices as control variables.

$$\begin{aligned}\Delta y_{t+1}(i) &= a(i) + b_1[\hat{\beta}_1 \pi_{t-1}^{food} + \hat{\beta}_2 s_t^{food}(i)\pi_{t-1}^{food}] \\ &\quad + b_2\hat{\beta}_3 \pi_{t-1}^{energy} + b_3 \hat{\varepsilon}_t(i) + c_1 \pi_{t+1}^{food} \\ &\quad + c_2 \pi_{t+1}^{energy} + c_3 \pi_{t+1}^{others} + \varepsilon_t(i). \qquad (5)\end{aligned}$$

Table 11 shows the estimation results of (5). The results about the sign and statistical significance of (b_1, b_2, b_3) in Table 10 remain unchanged[15).

2.6 Summary of Empirical Results

In this section, we empirically investigated households' inflation expectations formation and its implications for their inter-temporal consumption allocations. Specifically, we connected the literature on the determinants of households' inflation expectations formation and the literature on the relationship between households' inflation expectations and their underlying inter-temporal consumption allocations.

As is consistent with existing studies on the link between households' shopping experience and their inflation expectations, heterogeneity of households' inflation expectations can be partly accounted for by their shopping experience on daily products (food) and energy-related products. We also find that the changes in households' inflation expectations lead to changes in their inter-temporal consumption allocations, which is consistent with existing research on the relationship between households' inflation expectations and their underlying consumption decisions.

The new findings of our study are the state-dependence of the relationship between households' inflation expectations and their underlying consumption decisions: (1) households do not adjust their inter-temporal consumption allocations because of the changes in households' inflation expectations along with changes in recent food and energy prices; and (2) households adjust their inter-temporal consumption allocations because of the changes in households' inflation expectations caused by other factors.

We interpret these results as follows. Households do not adjust their inter-temporal consumption allocations if they change their inflation expectations along with recent changes in food and energy prices. This is because the changes in their inflation expectations are driven by changes in relative prices of food and energy prices and they do not expect changes in other prices in the future. Food- and energy-related products are daily necessities and thus households' inter-temporal elasticity of substitution on these items is expected to be low and the changes in households' expectations on relative prices of food and energy do not lead to changes in their consumptions.

By contrast, households do adjust their inter-temporal consumption allocations if they change their inflation expectations by other factors. This is because the changes in their inflation expectations are linked to the shift in their expectations on the macroeconomic conditions. Moreover, households' inter-temporal elasticity of substitution on some of the products are expected to be high, thereby leading to the changes in their inter-temporal consumption allocations.

In the next section, we formalize aforementioned interpretation. Specifically, we extend canonical consumption models and show that predictions from the model are

Table 11. Estimation Results for the Euler Equation: Role of Inflation Experience, Robustness Check.

Dependent variable: Changes in nominal expenditure from one year ago
minus changes in nominal income from one year ago

	(1)	(2)	(3)	(4)	(5)
Food price factors	−0.24	−0.50***	−0.33*	−0.27	−0.43
(when planned)	(0.11)	(0.14)	(0.19)	(0.26)	(0.28)
× Birth year		0.48			
(dummy: 1930–1959)		(0.51)			
× Male			0.16		
(dummy)			(0.33)		
× University graduate				0.03	
(or higher, dummy)				(0.23)	
× Little saving					0.32
(dummy)					(0.25)
Energy price factors	0.01	0.06	−0.01	−0.11	0.07
(when planned)	(0.13)	(0.35)	(0.15)	(0.10)	(0.15)
× Birth year		0.10			
(dummy: 1930–1959)		(0.43)			
× Male			0.01		
(dummy)			(0.24)		
× University graduate				0.43**	
(or higher, dummy)				(0.22)	
× Little saving					−0.08
(dummy)					(0.18)
Other factors	−0.09**	−0.15**	−0.17***	−0.07*	−0.21**
(when planned)	(0.04)	(0.06)	(0.06)	(0.04)	(0.11)
× Birth year		0.11***			
(dummy: 1930–1959)		(0.04)			
× Male			0.15**		
(dummy)			(0.06)		
× University graduate				−0.10	
(or higher, dummy)				(0.12)	
× Little saving					0.18*
(dummy)					(0.10)
CPI, food	−0.26***	−0.25***	−0.26***	−0.25***	−0.25***
	(0.08)	(0.08)	(0.08)	(0.08)	(0.08)
CPI, energy	−0.05***	−0.05***	−0.05***	−0.05***	−0.05***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
CPI	−0.25*	−0.26*	−0.25*	−0.25*	−0.26*
ex. food and energy	(0.15)	(0.15)	(0.15)	(0.14)	(0.15)
Intercept	2.37***	2.37***	2.38***	2.37***	2.36***
	(0.11)	(0.11)	(0.11)	(0.10)	(0.11)
Estimation period	2010–2018	2010–2018	2010–2018	2010–2018	2010–2018
R-squared	0.46	0.46	0.46	0.46	0.46
Observations	12174	12174	12174	12167	12174
Number of households	4190	4190	4190	4187	4190
Individual fixed effect	Yes	Yes	Yes	Yes	Yes
Time fixed effect	No	No	No	No	No

Note) Robust standard errors in parentheses. ***, **, and * denote significance at the 1%, 5%, and 10% level, respectively. The coefficients are estimated using WLS. For birth year dummy, the baseline category is 1960–1989. Little saving refers to the answer "I am so occupied with my daily life that I cannot save much money."

consistent with our narrative interpretation given above.

3. The Model

We consider a model of households' inter-temporal consumption allocations. The economy is divided into many regions, and each region is populated by a representative household. The time is indexed by $t \in \{, -1, 0, 1, , T\}$, and the households' decision is considered in period 0. There exist two types of goods: good A and good B. Good A represents the food- and energy-related products; they face large relative price shocks. Meanwhile, good B represents goods and services excluding food and energy, and their prices are assumed to depend on more stable aggregate macroeconomic conditions. Importantly, we assume that the degree of inter-temporal elasticity of substitution is different between these two goods. Otherwise, the model is a canonical consumption allocation model, except for the information structure we describe momentarily. In the following, we analyze the household's belief updating process and inter-temporal consumption allocations in a certain region.

3.1 Set-up

The representative household in each region maximizes the following utility.

$$\max_{\{C_t^A, C_t^B\}} \sum_{t=0}^{T} \beta^t \mathbb{E}_0 \left[\frac{(C_t^A)^{1-\sigma_A}}{1-\sigma_A} + \frac{(C_t^B)^{1-\sigma_B}}{1-\sigma_B} \right], \quad (6)$$

where C_t^X indicates the consumption to good $X \in \{A, B\}$ in period t and $(\sigma_A^{-1}, \sigma_B^{-1})$ is inter-temporal elasticity of substitution in consumption regarding the consumption of goods A and B, respectively. For simplicity, we assume additivity of the utility across different goods. Moreover, σ_A^{-1} is assumed to be smaller than σ_B^{-1}.

The budget constraint in each period is given as follows:

$$P_0^A C_0^A + P_0^B C_0^B = I - S_0, \quad (7)$$

for period 0 and, for period $t \in \{1, 2, , T\}$,

$$P_t^A C_t^A + P_t^B C_t^B + S_t = (1+R_t) S_{t-1}, \quad (8)$$

where P_t^X indicates the price of good $X \in \{A, B\}$ in period $t \in \{0, 1, 2, , T\}$. I is an endowment in the initial period. S_t is the saving and must be non-negative in period T.

R_t indicates the nominal interest rate. We assume that the economy hits the lower bound in all periods from period 0, and thus, $1+R_t=1$ holds for all $t \in \{0, 1, 2, , T\}$.

By combining the budget constraint in each period, equations (7) and (8), we obtain the following single inter-temporal budget constraint.

$$\sum_{t=0}^{T} [P_t^A C_t^A + P_t^B C_t^B] = I.$$

To map our model predictions into our empirical results, we define the price index and aggregate consumption for the household as follows.

$$P_t \equiv P_t^A \bar{C}^A + P_t^B \bar{C}^B,$$

$$C_t \equiv \frac{P_t^A C_t^A + P_t^B C_t^B}{P_t},$$

where $(\bar{C}^A, \bar{C}^B)$ are consumption levels in the non-stochastic steady state. Here, no shock occurs, and the relative prices of the good A and the good B are normalized by 1.

3.2 Euler Equation

In the following, we denote the logarithm of the original variable by small letter as $x = \log X$. Similarly, we denote deviation of the variable from the non-stochastic steady state by small letter with the hat as $\hat{x} = \log X - \log \bar{X}$. By solving the household's problem characterized by equations (6), (7) and (8), we obtain the Euler equations for two goods as follows.

Lemma 1 *(i) The optimal inter-temporal consumption allocation of the household about good A and B is*

$$\mathbb{E}_0[\hat{c}_1^A - \hat{c}_0^A] = -\frac{1}{\sigma_A} \mathbb{E}_0[\pi_1^A], \quad (9)$$

$$\mathbb{E}_0[\hat{c}_1^B - \hat{c}_0^B] = -\frac{1}{\sigma_B} \mathbb{E}_0[\pi_1^B]. \quad (10)$$

(ii) The optimal inter-temporal consumption allocation of the household about consumption is

$$\mathbb{E}_0[\hat{c}_1-\hat{c}_0] = -\omega\frac{1}{\sigma_A}\mathbb{E}_0[\pi_1^A] - (1-\omega)\frac{1}{\sigma_B}\mathbb{E}_0[\pi_1^B], \quad (11)$$

where $\omega \equiv \dfrac{\bar{C}^A}{\bar{C}^A+\bar{C}^B} \in (0,1)$.

Proof: See Appendix B. 1.□

Lemma 1 states that the expected growth rate of the consumption of the good between two periods solely depends on the underlying inflation expectations of the good (equations (9) and (10)) because the nominal interest rate is zero. In addition, the growth rate of consumption can be expressed as a weighted sum of sectoral inflation (equation (11)).

An important observation is that the changes in the households' inflation expectations on each good ($\mathbb{E}_0[\pi_1^A]$, $\mathbb{E}_0[\pi_1^B]$) cause smaller adjustments of the households' consumption allocation ($\mathbb{E}_0[\hat{c}_1-\hat{c}_0]$) if the inter-temporal elasticity of substitution in consumption for the households on the good ($\sigma_A^{-1}, \sigma_B^{-1}$) is low (equation (11)). We then examine the dynamics of the households' inflation expectations on each good ($\mathbb{E}_0[\pi_1^A]$, $\mathbb{E}_0[\pi_1^B]$).

3.3 Inflation Expectations Formation

3.3.1 Inflation dynamics and information structures

We assume realistic inflation dynamics. First, we assume that the dynamics of inflation of both goods A (energy- and food-related products) and B are somewhat persistent. Second, we assume that the inflation dynamics of good A is driven mainly by relative price shocks.

Specifically, we set-up the following inflation dynamics in a reduced form and estimate the parameters with Japanese data for quantitative exercise[16].

$$p_t^A = \theta_t+\varepsilon_t^R+\varepsilon_t^A, \quad (12)$$

$$p_t^B = \theta_t+\varepsilon_t^R, \quad (13)$$

where θ_t is the linear combination of aggregate variables and ε_t^R is the linear combination of region-specific variables, which are assumed uncorrelated to each other. ε_t^A is a relative price shock.

The law of a motion of the variables is given by

$$\theta_t = \theta_{t-1}+\varepsilon_t+\gamma, \quad (14)$$

$$\varepsilon_t = \rho\varepsilon_{t-1}+\delta_t^\theta, \quad (15)$$

$$\varepsilon_t^R = \varepsilon_{t-1}^R+\delta_t^R, \quad (16)$$

$$\varepsilon_t^A = \varepsilon_{t-1}^A+\eta_t^A, \quad (17)$$

$$\eta_t^A = \rho_A\eta_{t-1}^A+\delta_t^A, \quad (18)$$

where γ is fixed (during the same monetary policy regime), and for analytical simplicity, we assume $\eta_{t-s}^A=\delta_{t-s}^A=\delta_{t-s}^\theta=0$, for $s=0, 1, 2, ,$ until the period 0. Given equations (12), (13), (14), (15), (16), (17), and (18), inflation dynamics ($\pi_t^A=p_t^A-p_{t-1}^A$ and $\pi_t^B=p_t^B-p_{t-1}^B$) is expressed as follows.

$$\pi_t^A = \varepsilon_t+\delta_t^R+\eta_t^A+\gamma, \quad (19)$$

$$\pi_t^B = \varepsilon_t+\delta_t^R+\gamma. \quad (20)$$

The distributions of $\delta_t^\theta, \delta_t^R$ and δ_t^A are assumed as

$$\delta_t^\theta \sim \mathcal{N}(0,\sigma_\theta^2), \quad (21)$$

$$\delta_t^R \sim \mathcal{N}(0,\tau_R^2), \quad (22)$$

$$\delta_t^A \sim \mathcal{N}(0,\tau_A^2). \quad (23)$$

Note that by taking logarithm and the first-order approximation of

$$\frac{P_t}{P_{t-1}} \equiv \frac{P_t^A\bar{C}^A+P_t^B\bar{C}^B}{P_{t-1}^A\bar{C}^A+P_{t-1}^B\bar{C}^B} = \frac{P_t^B}{P_{t-1}^B}\frac{\frac{P_t^A}{P_t^B}\bar{C}^A+\bar{C}^B}{\frac{P_{t-1}^A}{P_{t-1}^B}\bar{C}^A+\bar{C}^B},$$

around the non-stochastic steady state, the aggregate inflation rate is expressed as

$$\pi_t = \pi_1^B+\omega(p_t^A-p_t^B)-\omega(p_{t-1}^A-p_{t-1}^B) = \omega\pi_t^A+(1-\omega)\pi_1^B,$$

where $\pi_t=\ln p_t-\ln p_{t-1}$.

The key setting of the information structure is that the households in period t cannot observe $\theta_t, \varepsilon_t^R$, and ε_t^A directly, but they can observe p_t^A and p_t^B. Namely, they can observe the changes in prices, but they cannot observe the distinct factors behind the price changes. Therefore, they infer the contribution of each variable ($\{\theta_t, \varepsilon_t^R, \varepsilon_t^A\}$) to price changes ($\{p_t^A, p_t^B\}$) following Bayes' law. These information structures capture the situation that the households rely mainly on their shopping experiences when they form their inflation expectations as indicated by existing empirical literature.

3.3.2 Bayesian updating

Under the information structures characterized by equations (12), (13), (14), (15), (16), (17), and (18) and distributions (21), (22), and (23), we derive the household's inflation expectations as follows.

Lemma 2 *(i) The household's inflation expectations about goods A and B are, respectively, given as*

$$\mathbb{E}_0[\pi_1^A] = \rho\frac{\tau_R^{-2}}{\tau_R^{-2}+\sigma_\theta^{-2}}(\pi_0^B-\gamma) + \rho_A\frac{[\sigma_\theta^2+\tau_R^2]^{-1}}{[\sigma_\theta^2+\tau_R^2]^{-1}+\tau_A^{-2}}(\pi_0^A-\gamma)+\gamma, \quad (24)$$

$$\mathbb{E}_0[\pi_1^B] = \rho\frac{\tau_R^{-2}}{\tau_R^{-2}+\sigma_\theta^{-2}}(\pi_0^B-\gamma)+\gamma. \quad (25)$$

(ii) The households' inflation expectations about aggregate price is given as

$$\mathbb{E}_0[\pi_1] = \omega\rho_A\frac{[\sigma_\theta^2+\tau_R^2]^{-1}}{[\sigma_\theta^2+\tau_R^2]^{-1}+\tau_A^{-2}}(\pi_0^A-\gamma) + \rho\frac{\tau_R^{-2}}{\tau_R^{-2}+\sigma_\theta^{-2}}(\pi_0^B-\gamma)+\gamma, \quad (26)$$

where $\omega \equiv \frac{\bar{C}^A}{\bar{C}^A+\bar{C}^B} \in (0,1)$.

Proof: See Appendix B. 2.□

Lemma 2 shows that the changes in the inflation rate of each good in the current period affect households' inflation expectations. This is because the households employ Bayesian updating of their beliefs about persistent shocks ($\delta_t^\theta, \delta_t^A$). This is our interpretation of the effects of shopping experience for households' inflation expectations formation observed in Section 2. 4. The equation (26) also indicates important observation that the effects of the changes in the inflation rates of goods A and B on the households expectations on aggregate inflation vary depending on the structural parameters of inflation dynamics ($\rho, \rho_A, \sigma_\theta^2, \tau_A^2, \tau_B^2, \tau_R^2$). Importantly, the aggregate inflation expectations ($\mathbb{E}_0[\pi_1]$) are affected by both: the expectations about the contribution of relative price shocks $\left(\omega\rho_A\frac{[\sigma_\theta^2+\tau_R^2]^{-1}}{[\sigma_\theta^2+\tau_R^2]^{-1}+\tau_A^{-2}}(\pi_0^A-\gamma)\right)$ and the expectations about the contribution of aggregate conditions $\left(\rho\frac{\tau_R^{-2}}{\tau_R^{-2}+\sigma_\theta^{-2}}(\pi_0^B-\gamma)+\gamma\right)$. However, the role of the inflation dynamics of good A (π_0^A) in shaping households' inflation expectations is different from that of good B (π_0^B). The households view the changes in the inflation of good B as a noisy signal for the changes in macroeconomic conditions, and thus, they update their inflation expectations by presuming the changes in future macroeconomic conditions. Meanwhile, the households regard the changes in the inflation of good A mainly as a noisy signal for the relative price shocks, and thus, they revise their inflation expectations by expecting the relative price shocks in the future[17].

3.4 Inflation Expectations and Consumption Plan

By combining lemma 1 and 2, we obtain the following relationship between the inflation expectations and consumption plan.

Proposition 1 *The household's consumption plan depends on each component of inflation expectations:*

$$\mathbb{E}_0[\hat{c}_1-\hat{c}_0] = -\omega\frac{1}{\sigma_A}\mathbb{E}_0[\pi_1^A]-(1-\omega)\frac{1}{\sigma_B}\mathbb{E}_0[\pi_1^B]$$
$$= -\omega\frac{1}{\sigma_A}\rho_A\frac{[\sigma_\theta^2+\tau_R^2]^{-1}}{[\sigma_\theta^2+\tau_R^2]^{-1}+\tau_A^{-2}}(\pi_0^A-\gamma)$$

$$-\left(\omega\frac{1}{\sigma_A}+(1-\omega)\frac{1}{\sigma_B}\right)$$
$$\left[\rho\frac{\tau_R^{-2}}{\tau_R^{-2}+\sigma_\theta^{-2}}(\pi_0^B-\gamma)+\gamma\right] \quad (27)$$
$$=-\omega\frac{1}{\sigma_A}\mathbb{E}_0^A[\pi_1]$$
$$-\left(\omega\frac{1}{\sigma_A}+(1-\omega)\frac{1}{\sigma_B}\right)\mathbb{E}_0^O[\pi_1], \quad (28)$$

where $\omega\equiv\frac{\bar{C}^A}{\bar{C}^A+\bar{C}^B}\in(0,1)$,

$$\mathbb{E}_0^A[\pi_1]\equiv\rho_A\frac{[\sigma_\theta^2+\tau_R^2]^{-1}}{[\sigma_\theta^2+\tau_R^2]^{-1}+\tau_A^{-2}}(\pi_0^A-\gamma),$$

$$\mathbb{E}_0^O[\pi_1]\equiv\rho\frac{\tau_R^{-2}}{\tau_R^{-2}+\sigma_\theta^{-2}}(\pi_0^B-\gamma)+\gamma.$$

Proof: By substituting equation (24) and (25) into equation (11), we obtain the result above.□

In equation (28) of proposition 1, $\mathbb{E}_0^A[\pi_1]$ corresponds to the changes in household's inflation expectations by food and energy price factors, and $\mathbb{E}_0^O[\pi_1]$ is equivalent to those by other factors. The impact of changes in inflation expectations by food and energy price factors ($\mathbb{E}_0^A[\pi_1]$) on the inter-temporal consumption allocation depends only on the inter-temporal elasticity of substitution in consumption regarding the consumption of good A (σ_A^{-1}). This is because the changes in inflation expectations by food and energy price factors ($\mathbb{E}_0^A[\pi_1]$) entail the changes in inflation expectations about good A, but not those about good B. Meanwhile, the impact of changes in inflation expectations by other factors ($\mathbb{E}_0^O[\pi_1]$) on the inter-temporal consumption allocation relies both on the inter-temporal elasticity of substitution in consumption regarding the consumption of goods A and B ($\sigma_A^{-1}, \sigma_B^{-1}$). This is because the changes in inflation expectations by other factors ($\mathbb{E}_0^O[\pi_1]$) imply changes in macroeconomic conditions and thus affect the inflation expectations about both goods. Hence, the equation indicates that the link between the households' aggregate inflation expectations and their inter-temporal consumption allocations could change depending on the factors shifting the households' aggregate inflation expectations.

Equation (27) of proposition 1 shows that changes in the inflation rate of each good in the current period affect households' inter-temporal consumption allocations, and the effects depend on the structural parameters of inflation dynamics ($\rho, \rho_A, \sigma_\theta^2, \tau_A^2, \tau_B^2, \tau_R^2$).

Proposition 2
$\left|\frac{\partial\mathbb{E}_0[\hat{c}_1-\hat{c}_0]}{\partial\mathbb{E}_0^A[\pi_1]}\right|<\left|\frac{\partial\mathbb{E}_0[\hat{c}_1-\hat{c}_0]}{\partial\mathbb{E}_0^O[\pi_1]}\right|$ *holds.*

Proof: From equation (28), $\left|\frac{\partial\mathbb{E}_0[\hat{c}_1-\hat{c}_0]}{\partial\mathbb{E}_0^A[\pi_1]}\right|=\omega\frac{1}{\sigma_A}<\omega\frac{1}{\sigma_A}+(1-\omega)\frac{1}{\sigma_B}=\left|\frac{\partial\mathbb{E}_0[\hat{c}_1-\hat{c}_0]}{\partial\mathbb{E}_0^O[\pi_1]}\right|$ holds.□

Inequality in the equation of proposition 2 shows that consumers adjust the expected growth of the consumption to a smaller extent if food and energy price factors drive the changes in their inflation expectations. Meanwhile, if other factors drive the changes in their inflation expectations, they adjust the expected growth of the consumption to a larger extent. This theoretical prediction explains our empirical observation in section 2. 5 when σ_A^{-1} is sufficiently small.

The result can be intuitively interpreted as follows. The changes in inflation expectations driven by changes in price of good A do not lead to changes in the expectations about the price of good B because the price of good A is mostly determined by relative price shocks. Therefore, the households adjust their inter-temporal consumption allocations of good A only slightly, because the inter-temporal elasticity of substitution regarding good A is low. Moreover, they do not adjust their inter-temporal consumption allocations of good B because they expect the price of

Table 12. Calibrated and Estimated Parameter Values in a Baseline Case.

ρ	Persistence of changes in aggregate variables	0.81
ρ_A	Persistence of changes in food and energy variables	0.43
σ_θ^2	The variance of changes in aggregate variables	0.51
τ_A^2	The variance of changes in food and energy variables	2.23
τ_R^2	The variance of regional shocks	0.23
ω	Proportion of the expenditure on food and energy	0.4
σ_A^{-1}	Inter-temporal elasticity of substitution, food and energy	0.2
σ_B^{-1}	Inter-temporal elasticity of substitution, non-food and energy	0.5

good B does not change much in the future. By contrast, if the changes in the price of good B drive the changes in inflation expectations, the households adjust their inter-temporal consumption allocations of good B.

3. 5 Mapping the Model to Empirics

This subsection demonstrates the explanatory power of the calibrated version of our model about our empirical observations in section 2.

3. 5. 1 Calibration and estimation strategy

To discipline our analysis, we estimate the parameters of the inflation dynamics using the data on regional consumer price indexes in 1985–2019 in Japan[18]. We then use the estimates for the values of parameters $(\rho, \rho_A, \sigma_\theta^2, \tau_A^2, \tau_R^2)$ to evaluate the model's prediction numerically. Appendix C shows the detailed explanation of our estimation strategy[19].

The proportion of the expenditure on food and energy is calibrated as 0.4 because the approximated values of the averages of the Engel's coefficients across the samples in each year is around 0.35, and we add the weight for energy-related products that is assumed to be about 0.05. For the inter-temporal elasticity of substitution in consumption of goods A and B, we set $\sigma_A^{-1}=0.2$ and $\sigma_B^{-1}=0.5$, respectively. The data are summarized in Table 12.

3. 5. 2 Inflation expectations formations

First, we examine the relationship between the households' shopping experience and their inflation expectations in equations (26). The contributions of the factors to inflation expectations (π_0^A, π_0^B) are given by

$$\frac{\partial \mathbb{E}_0[\pi_1]}{\partial \pi_0^A} = \omega\rho_A \frac{[\sigma_\theta^2+\tau_R^2]^{-1}}{[\sigma_\theta^2+\tau_R^2]^{-1}+\tau_A^{-2}}, \quad \frac{\partial \mathbb{E}_0[\pi_1]}{\partial \pi_0^B} = \rho \frac{\tau_R^{-2}}{\tau_R^{-2}+\sigma_\theta^{-2}}. \tag{29}$$

By substituting the parameters in Table 12 into the equations (29), we obtain

$$\frac{\partial \mathbb{E}_0[\pi_1]}{\partial \pi_0^A} \approx 0.13, \frac{\partial \mathbb{E}_0[\pi_1]}{\partial \pi_0^B} \approx 0.56.$$

Therefore, the theoretical prediction about the effects of food and energy price factors on inflation expectations $\left(\frac{\partial \mathbb{E}_0[\pi_1]}{\partial \pi_0^A} \approx 0.13\right)$ is in a range of the point estimates of $\frac{\partial \mathbb{E}_0[\pi_1]}{\partial \pi_0^A}$ for food prices and energy prices that are 0.21 and 0.05, respectively. Note that if τ_A^2, that is, the variance of relative price shocks on good A, is small, the effects of changes in inflation of good A do not lead to changes in inflation expectations (of the general price). That is, $\frac{\partial \mathbb{E}_0[\pi_1]}{\partial \pi_0^A}$ becomes smaller. This is because small τ_A^2 means that the aggregate inflation is affected by the relative price shocks on the good A only weakly.

3. 5. 3 Euler equation

We then evaluate the model on the relationship between the contributions of food and energy price factors and other factors to inflation expectations and the underlying inter-temporal consumption allocations in equation (28). The contributions of the factors to inflation expectations ($\mathbb{E}_0^A[\pi_1]$, $\mathbb{E}_0^O[\pi_1]$) are

$$\frac{\partial \mathbb{E}_0[\hat{c}_1-\hat{c}_0]}{\partial \mathbb{E}_0^A[\pi_1]} = -\omega\frac{1}{\sigma_A},$$
$$\frac{\partial \mathbb{E}_0[\hat{c}_1-\hat{c}_0]}{\partial \mathbb{E}_0^O[\pi_1]} = -\left(\omega\frac{1}{\sigma_A}+(1-\omega)\frac{1}{\sigma_B}\right). \quad (30)$$

As before, by substituting the parameters of Table 12 into the equations (30), we have

$$\frac{\partial \mathbb{E}_0[\hat{c}_1-\hat{c}_0]}{\partial \mathbb{E}_0^A[\pi_1]} \approx -0.08, \frac{\partial \mathbb{E}_0[\hat{c}_1-\hat{c}_0]}{\partial \mathbb{E}_0^O[\pi_1]} \approx -0.38,$$

which is consistent with the estimates in Table 10. Namely, the sensitivity of consumption to the changes in inflation expectations by food and energy price factors is not significant, and the sensitivity to the changes in inflation expectations by other factors is around −0.32. Note that if ω, that is, the weight of good A for the consumption basket in the non-stochastic steady state, is larger, the absolute value of $\frac{\partial \mathbb{E}_0[\hat{c}_1-\hat{c}_0]}{\partial \mathbb{E}_0^A[\pi_1]}$ takes larger values, and that of $\frac{\partial \mathbb{E}_0[\hat{c}_1-\hat{c}_0]}{\partial \mathbb{E}_0^O[\pi_1]}$ would be smaller. This is because the higher the weight of good $A(B)$ for the consumption basket, the more heavily the inter-temporal allocation of consumption depends on the inter-temporal consumption allocation of good $A(B)$.

Therefore, our model can replicate our empirical results with a reasonable set of parameters summarized in Table 12.

4. Concluding Remarks

Utilizing the micro-level panel dataset constructed on the basis of household surveys in Japan, we show the state-dependency of the link between the households' inflation expectations and their underlying inter-temporal consumption allocations. We find that changes in households' inflation expectations by the food and energy price fluctuations do not affect their inter-temporal consumption allocations, whereas changes in their inflation expectations owing to other factors lead to the adjustment of their inter-temporal consumption allocations. We then propose a model of households' inter-temporal consumption allocations that can consistently explain our empirical results with reasonable parameter values. Our finding provides a new insight into a recent discussion on inflation expectation and consumption. Our results suggest the necessity to carefully monitor the factors causing shifting inflation expectation to assess their impacts on the economy.

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A. Additional Results in Empirical Analysis

This Appendix explores the information reflected by the "other factors". Food and energy price factors capture most of the effects of recent shopping experiences on households' inflation expectations. Thus, other factors should be related to, among other things, households' shopping experience on other items and their economic outlook. We first regress households' expectations about the growth rate of the one year ahead aggregate nominal wages on inflation expectations. As shown in column (1) of Table 13, the inflation expectations have a positive correlation with the expected nominal aggregate wage[20].

We next regress households' expectations about the growth rate of the one year ahead aggregate nominal wages on "food price factors", "energy price factors", and "other factors" of the inflation expectations, respectively. Food price factors and energy price factors have a negative relationship with the expected wages (columns (2) and (3)). By contrast, the relationship between other factors and the expected wages is positive and significant (column (4)), which

Table 13. Estimation Results: Expected Wage and Inflation Expectations.

Dependent variable: Expected growth of nominal wage over the next year.

	(1)	(2)	(3)	(4)
Inflation expectations	0.16***			
	(0.00)			
Food price factors		−0.01***		
		(0.00)		
Energy price factors			−0.34***	
			(0.00)	
Other factors				0.12***
				(0.00)
Intercept	5.13***	5.35***	5.26***	5.32***
	(0.00)	(0.00)	(0.00)	(0.00)
Estimation period	2017-2018	2017-2018	2017-2018	2017-2018
Adjusted R-squared	0.69	0.74	0.68	0.74
Observations	3533	2834	3556	2829
Number of households	2034	1741	2043	1737
Individual fixed effect	Yes	Yes	Yes	Yes
Time fixed effect	Yes	Yes	Yes	Yes

Note) Robust standard errors in parentheses. *** denotes significance at the 1% level.

is the same in column (1). These results suggest that households lower their income outlook in real terms when they increase their inflation expectations based on the shopping experience on food and energy-related products (i.e., relative price changes) whereas the increase in households' inflation expectations driven by other factors does not lead to the downward revision of the expected real wage.

We interpret the observations in Table 13 as follows. If households change their inflation expectations along with recent changes in food and energy prices, they expect mainly relative price changes about food and energy and do not expect the shift of general prices. Therefore, they do not expect the changes in nominal wages which should be linked to the general prices. On the other hand, if households change their inflation expectations by other factors, they expect the shift of general prices and nominal wages.

For robustness checks, we conduct the same exercise by changing the explained variable from the expected growth rate of nominal wage to the expected growth rate of household's own nominal income, and the estimation results are shown in Table 14. We then confirm that our main results in Table 13 remain intact; that is, only other factors have a positive relationship with the expected growth rate of nominal wages. Meanwhile, the correlations between food and energy price factors and the expected growth rate of their own nominal income are not statistically significant unlike the case of the expected growth rate of nominal wages.

B. Proofs

B. 1 Proof of Lemma 1

Optimality conditions. We set the Lagrangian for the representative household's maximization problem as follows.

$$\max_{\{C_t^A, C_t^B\}} \sum_{t=0}^{T} \beta^t \mathbb{E}_0 \left[\frac{(C_t^A)^{1-\sigma_A}}{1-\sigma_A} + \frac{(C_t^B)^{1-\sigma_B}}{1-\sigma_B} \right] + \lambda \left[I - \sum_{t=0}^{T} [P_t^A C_t^A + P_t^B C_t^B] \right],$$

where λ is Lagrange multiplier. The first-order conditions with respect to $\{C_0^A, C_0^B, C_1^A, C_1^B\}$ are, respectively, given as follows.

$$(C_0^A)^{-\sigma_A} - \lambda P_0^A = 0,$$
$$(C_0^B)^{-\sigma_B} - \lambda P_0^B = 0,$$
$$\mathbb{E}_0[\beta (C_1^A)^{-\sigma_A} - \lambda P_1^A] = 0,$$

Table 14. Estimation Results: Expected Incom and Inflation Expectations.

Dependent variable: Expected growth of nominal income over the next year.

	(1)	(2)	(3)	(4)
Inflation expectations	0.10***			
	(0.03)			
Food price factors		0.07		
		(0.08)		
Energy price factors			0.28	
			(0.24)	
Other factors				0.09***
				(0.03)
Intercept	−0.94***	−0.81***	−0.85***	−0.79***
	(0.03)	(0.01)	(0.02)	(0.00)
Estimation period	2017-2018	2017-2018	2017-2018	2017-2018
Adjusted R-squared	0.40	0.42	0.40	0.42
Observations	2606	7940	3213	7738
Number of households	5140	4671	5187	4642
Individual fixed effect	Yes	Yes	Yes	Yes
Time fixed effect	Yes	Yes	Yes	Yes

Note) Robust standard errors in parentheses. *** denotes significance at the 1% level.

$$\mathbb{E}_0[\beta(C_1^B)^{-\sigma_B}-\lambda P_1^B]=0.$$

Using these equations, we obtain the following conditions for inter-temporal consumption allocations of good A and B.

$$\mathbb{E}_0\left[\left(\frac{C_0^A}{C_1^A}\right)^{-\sigma_A}\right]=\beta\,\mathbb{E}_0\left[\left(\frac{P_0^A}{P_1^A}\right)\right]=\beta\,\mathbb{E}_0\left[\frac{1}{1+\Pi_1^A}\right], \quad (31)$$

$$\mathbb{E}_0\left[\left(\frac{C_0^B}{C_1^B}\right)^{-\sigma_B}\right]=\beta\,\mathbb{E}_0\left[\frac{1}{1+\Pi_1^B}\right]. \quad (32)$$

Similarly, we also obtain the conditions for intra-temporal allocation between good A and good B as follows.

$$\frac{(C_0^A)^{-\sigma_A}}{(C_0^B)^{-\sigma_B}}=\frac{P_0^A}{P_0^B}, \quad (33)$$

$$\mathbb{E}_0\left[\frac{(C_1^A)^{-\sigma_A}}{(C_1^B)^{-\sigma_B}}\right]=\mathbb{E}_0\left[\frac{P_1^A}{P_1^B}\right]. \quad (34)$$

Log-linearization. By taking logarithm and first-order approximation of equations (31), (32), (33) and (34) around the non-stochastic steady state, we obtain the following conditions.

$$\mathbb{E}_0[\hat{c}_1^A-\hat{c}_0^A]=-\frac{1}{\sigma_A}\mathbb{E}_0[\pi_1^A], \quad (35)$$

$$\mathbb{E}_0[\hat{c}_1^B-\hat{c}_0^B]=-\frac{1}{\sigma_B}\mathbb{E}_0[\pi_1^B], \quad (36)$$

$$-\sigma_A\hat{c}_0^A+\sigma_B\hat{c}_0^B=p_0^A-p_0^B, \quad (37)$$

$$-\sigma_A\,\mathbb{E}_0[\hat{c}_1^A]+\sigma_B\,\mathbb{E}_0[\hat{c}_1^B]=\mathbb{E}_0[p_1^A-p_1^B]. \quad (38)$$

Note that conditions (35) and (36) can be reconciled with conditions (37) and (38) as follows. If conditions (35) and (36) are satisfied, then the following equation must hold.

$$\sigma_A\,\mathbb{E}_0[\hat{c}_1^A-\hat{c}_0^A]-\sigma_B\,\mathbb{E}_0[\hat{c}_1^B-\hat{c}_0^B]=-\mathbb{E}_0[p_1^A-p_0^A]+\mathbb{E}_0[p_1^B-p_0^B].$$

If conditions (37) and (38) are satisfied, the equation above also holds.

The consumption $\left(C_t\equiv\frac{P_t^A C_t^A+P_t^B C_t^B}{P_t}\right)$ is expressed as follows.

$$C_t=\frac{\left(\frac{P_t^A}{P_t^B}\right)C_t^A+C_t^B}{\left(\frac{P_t^A}{P_t^B}\right)\bar{C}^A+\bar{C}^B}$$

$$\Leftrightarrow \ln C_t=\ln\left(\left(\frac{P_t^A}{P_t^B}\right)C_t^A+C_t^B\right)-\ln\left(\left(\frac{P_t^A}{P_t^B}\right)\bar{C}^A+\bar{C}^B\right)$$

$$\Leftrightarrow \frac{C_t-\bar{C}}{\bar{C}}\approx\frac{\bar{C}^A}{\bar{C}^A+\bar{C}^B}\frac{C_t^A-\bar{C}^A}{\bar{C}^A}+\frac{\bar{C}^B}{\bar{C}^A+\bar{C}^B}\frac{C_t^B-\bar{C}^B}{\bar{C}^B}$$

$$+\frac{\bar{C}^A}{\bar{C}^A+\bar{C}^B}\left(\frac{P_t^A}{P_t^B}-1\right)$$
$$-\frac{\bar{C}^A}{\bar{C}^A+\bar{C}^B}\left(\frac{P_t^A}{P_t^B}-1\right)$$
$$\Leftrightarrow \hat{c}_t=\frac{\bar{C}^A}{\bar{C}^A+\bar{C}^B}\hat{c}_t^A+\left(1-\frac{\bar{C}^A}{\bar{C}^A+\bar{C}^B}\right)\hat{c}_t^B.$$

Therefore, using (35) and (36),

$$\begin{aligned}\mathbb{E}_0[\hat{c}_1-\hat{c}_0] &= \frac{\bar{C}^A}{\bar{C}^A+\bar{C}^B}\mathbb{E}_0[\hat{c}_1^A-\hat{c}_0^A] \\ &\quad+\left(1-\frac{\bar{C}^A}{\bar{C}^A+\bar{C}^B}\right)\mathbb{E}_0[\hat{c}_1^B-\hat{c}_0^B] \\ &= -\frac{\bar{C}^A}{\bar{C}^A+\bar{C}^B}\frac{1}{\sigma_A}\mathbb{E}_0[\pi_1^A] \\ &\quad-\left(1-\frac{\bar{C}^A}{\bar{C}^A+\bar{C}^B}\right)\frac{1}{\sigma_B}\mathbb{E}_0[\pi_1^B],\end{aligned}$$

holds. □

B. 2 Proof of Lemma 2

To begin with, we show the households' updating process of their beliefs about current economy. Denote the expectations operator after observing p_0^A and p_0^B by $\mathbb{E}_0$. Then,

$$\mathbb{E}_0[\eta_0^A]=\frac{[\sigma_\theta^2+\tau_R^2]^{-1}}{[\sigma_\theta^2+\tau_R^2]^{-1}+\tau_A^{-2}}(\pi_0^A-\gamma),$$
$$\mathbb{E}_0[\varepsilon_0]=\frac{\tau_R^{-2}}{\tau_R^{-2}+\sigma_\theta^{-2}}(\pi_0^B-\gamma),$$

hold.

Next, we derive the inflation expectations as follows. With respect to the expectations on each shock,

$$\begin{aligned}\mathbb{E}_0[\eta_1^A] &= \mathbb{E}_0[\rho_A\eta_0^A+\delta_1^A] \\ &= \rho_A\frac{[\sigma_\theta^2+\tau_R^2]^{-1}}{[\sigma_\theta^2+\tau_R^2]^{-1}+\tau_A^{-2}}(\pi_0^A-\gamma),\\ \mathbb{E}_0[\delta_1^R] &= 0,\\ \mathbb{E}_0[\varepsilon_1] &= \mathbb{E}_0[\rho\varepsilon_0+\delta_\theta^1] \\ &= \rho\frac{\tau_R^{-2}}{\tau_R^{-2}+\sigma_\theta^{-2}}(\pi_0^B-\gamma),\end{aligned}$$

hold. Therefore, the inflation expectations about each good is

$$\begin{aligned}\mathbb{E}_0[\pi_1^A] &= \mathbb{E}_0[\varepsilon_1+\delta_1^R+\eta_1^A+\gamma] \\ &= \rho\frac{\tau_R^{-2}}{\tau_R^{-2}+\sigma_\theta^2}(\pi_0^B-\gamma) \\ &\quad+\rho_A\frac{[\sigma_\theta^2+\tau_R^2]^{-1}}{[\sigma_\theta^2+\tau_R^2]^{-1}+\tau_A^{-2}}(\pi_0^A-\gamma)+\gamma,\end{aligned}$$

$$\begin{aligned}\mathbb{E}_0[\pi_1^B] &= \mathbb{E}_0[\varepsilon_1+\delta_1^R+\gamma] \\ &= \rho\frac{\tau_R^{-2}}{\tau_R^{-2}+\sigma_\theta^{-2}}(\pi_0^B-\gamma)+\gamma.\end{aligned}$$

Aggregate inflation expectations is

$$\begin{aligned}\mathbb{E}_0[\pi_1] &= \omega\,\mathbb{E}_0[\pi_1^A]+(1-\omega)\,\mathbb{E}_0[\pi_1^B] \\ &= \omega\rho_A\frac{[\sigma_\theta^2+\tau_R^2]^{-1}}{[\sigma_\theta^2+\tau_R^2]^{-1}+\tau_A^{-2}}(\pi_0^A-\gamma) \\ &\quad+\rho\frac{\tau_R^{-2}}{\tau_R^{-2}+\sigma_\theta^{-2}}(\pi_0^B-\gamma)+\gamma. \square\end{aligned}$$

C. Estimation Strategy of Inflation Dynamics

This appendix explains our estimation strategy of inflation dynamics in the model (equations (19) and (20)) using Japanese data of regional (47 capital cities) and product-level consumer price indices (the inflation rate of food- and energy- related product for π_t^A and the inflation of all items excluding food and energy for π_t^B). The sample period is 1985–2019 and thus we have 35 observations in each city.

The equations (19) and (20) are summarized as follows.

$$\pi_t^A(i)=\rho\varepsilon_{t-1}+\delta_t^\theta+\delta_t^R(i)+\rho_A\eta_{t-1}^A+\delta_t^A+\gamma_t,$$
$$\pi_t^B(i)=\rho\varepsilon_{t-1}+\delta_t^\theta+\delta_t^R(i)+\gamma_t.$$

where $\delta_t^\theta\sim\mathcal{N}(0,\sigma_\theta^2)$, $\delta_t^R(i)\sim\mathcal{N}(0,\tau_R^2)$, and $\delta_t^A\sim\mathcal{N}(0,\tau_A^2)$. $(\pi_t^A(i),\pi_t^B(i))$ are inflation rates of goods A and B in city $i\in\{1,2,3,,47\}$ and $\delta_t^R(i)$ is the regional shock in city $i\in\{1,2,3,,47\}$. The period t takes $t\in\{1985, 2019\}$. The number of total observation is thus $47\times35=1645$.

The parameters for our interest are $(\rho,\rho_A,\sigma_\theta^2,\tau_A^2,\tau_R^2,\gamma_t)$. The unobservable variables are $(\varepsilon_{t-1},\delta_t^\theta,\delta_t^R(i),\eta_{t-1}^A,\delta_t^A)$ and the observable variables are $(\pi_t^A(i),\pi_t^B(i))$. We estimate these parameters step by step as follows.

First, we estimate the parameters (ρ_A,τ_A^2). By subtracting $\pi_t^B(i)$ from $\pi_t^A(i)$, we obtain the following equation.

$$\begin{aligned}\pi_t^A(i)-\pi_t^B(i) &= \rho_A\eta_{t-1}^A+\delta_t^A \\ &= \rho_A^2\eta_{t-2}^A+\rho_A\delta_{t-1}^A+\delta_t^A \\ &= \rho_A(\pi_{t-1}^A(i)-\pi_{t-1}^B(i))+\delta_t^A.\end{aligned}$$

$\pi_t^A(i) - \pi_t^B(i)$ and $\pi_{t-1}^A(i) - \pi_{t-1}^B(i)$ are observable, and $\delta_t^A \sim \mathcal{N}(0, \tau_A^2)$ is assumed to be white noise; hence, we estimate ρ_A by ordinary least squares. We then estimate τ_A^2 as the variance of error terms in the regression. The estimates are given by,

$$(\rho_A, \tau_A^2) = (0.43, 2.23).$$

Next, we estimate other parameters $\{\rho, \sigma_\theta^2, \tau_R^2, \gamma\}$. In so doing, we employ kalman filtering with the following observation equation and state equation. We set diffuse priors in the initial prior.

$$\text{Observation equation: } \pi_t^B(i) = \rho\varepsilon_{t-1} + \delta_t^\theta + \delta_t^R(i) + \gamma_t,$$

$$\text{State equation: } \varepsilon_t = \rho\varepsilon_{t-1} + \delta_t^\theta,$$

where,

$$\delta_t^\theta \sim \mathcal{N}(0, \sigma_\theta^2),$$

$$\delta_t^R(i) \sim \mathcal{N}(0, \tau_R^2),$$

$$\gamma_t = \gamma_0 D[t < 2010] + \gamma_1 D[2010 \le t \le 2012] + \gamma_2 D[t > 2012].$$

We assume that γ_t changed in 2010 and 2013. The estimates of the parameters are

$$(\rho, \rho_A, \sigma_\theta^2, \tau_A^2, \tau_R^2, \gamma_0, \gamma_1, \gamma_2) = (0.81, 0.43, 0.51, 2.23, 0.23, 0.54, 0.78, 0.97).$$

Notes

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1) The influence is also seen in the literature on government spending multipliers (Christiano, Eichenbaum, and Rebelo 2011).

2) Ueda (2010) found a similar result in Japan using aggregate data.

3) Several studies find a consistency, at least partially, between consumers' inflation expectations formation and the rational inattention framework developed by Sims (2003). For example, Cavallo, Cruces, and Perez-Truglia (2017) and Dräger and Lamla (2017) found the link between aggregate inflation volatility and consumers' inflation expectations. Ichiue, Koga, Okuda, and Ozaki (2019) showed that observed heterogeneity in patterns of Japanese consumers' inflation expectations formation is consistent with the rational inattention framework.

4) Ichiue, Koga, Okuda, and Ozaki (2019) and Nakajima (2020) examined the households' consumption decisions using the same dataset.

5) The maximum number of households is 6,181 in the 2009 wave, and the minimum is 1,696 in the 2018 wave.

6) The first and last categories do not have the midpoint as they indicate open ranges. On the inflation expectations, we assign minus 5% for the first question "Decrease by at least 4.5%." As a more statistical approach, a generalized beta distribution or a spline extrapolation for the first and last categories could be used.

7) Kamada, Nakajima, and Nishiguchi (2015) showed the heterogeneity of Japanese households' inflation expectations using the "Opinion Survey" conducted by the Bank of Japan.

8) See, e. g., Jonung (1981), Bryan and Venkatu (2001), Souleles (2004), Clark and Davig (2008), Blanchflower and MacCoille (2009), Pfajfar and Santoro (2009), Coibion and Gorodnichneko (2015a, b), Wong (2015), and D'Acunto *et al.* (2019).

9) In April 2014, the consumption tax rate was increased. National statistics show that consumption increased abruptly right before the tax rate hike mainly around January to March 2014. Our data do not include the year 2014; hence, we do not observe any significant influence of the tax rate hike.

10) This is a so-called adaptive nature of inflation expectations (Nishino, Yamamoto, Kitahara, and Nagahata 2016) or intrinsic persistence in inflation expectations (Fuhrer 2017a, b).

11) This formulation is a linear approximation of the original Euler equation derived from a standard theoretical model. We omit higher conditional moments by assuming that they are approximately time-invariant and therefore captured by the individual fixed effect. For further details, see, for example, Attanasio and Low (2004), Attanasio and Weber (2010), and Jappelli and Pistaferri (2010, 2017).

12) We use the answers to the question "I am so occupied with my daily life that I cannot save much money" as a proxy for the degree of borrowing constraint. We exclude households changing the number of their household members through the sample periods. We also exclude a time fixed effect because it

would reduce the rank of the coefficient's covariance matrix in computing robust standard errors.

13) If the households face tight borrowing constraints, the changes in households' income could affect the changes in consumption growth. However, as shown in Table 9, a cross term for the inflation expectations and borrowing constraint on expected consumption growth is not statistically significant. This evidence implies that most of the samples might not hit their borrowing constraint after the global financial crisis.

14) We recognize that inflation expectations are intrinsically endogenous in the entire model. We extract the effect of control variables from the inflation expectations, but the other factors may cause an endogeneity issue in the regression. Finding an appropriate instrument to solve the issue is challenging; thus, we leave it as future work.

15) In addition, to explore the difference in the property of inflation expectations in these two cases, we regress their nominal aggregate-wage expectations on their inflation expectations driven by each factor (food price factors, energy price factors, and other factors). We find a positive relationship between changes in households' inflation expectations caused by other factors and their expectations on nominal aggregate wages in one year. By contrast, the changes in households' inflation expectations along with changes in recent food and energy prices do not have a statistically significant relationship with their expectations on aggregate nominal wage. For details, see Appendix A.

16) The law of motion of the reduced-form inflation dynamics basically follows Vellekoop and Wiederholt (2017).

17) The households do not use the inflation dynamics of good A as a noisy signal for the changes in aggregate conditions because it does not provide extra information on macroeconomic conditions if the households observe the inflation dynamics of good B. Note that the inflation dynamics of good A is the sum of the inflation dynamics of good B (i.e., the noisy signal for the macroeconomic conditions) and additional noise (i.e., relative price shocks).

18) For the details of the statistics, see https://www.stat.go.jp/english/data/cpi/index.html.

19) Regarding the parameter γ, the Bank of Japan introduced the inflation goal at one percent in 2012 and the inflation target at two percent in 2013. We estimate γ by assuming that it is fixed before the Global Financial Crisis, and that it shifted to some extent up to the introduction of the inflation target. The estimation results for γ are 0.54 (1985–2009), 0.78 (2010–2012), and 0.97 (2013–2019).

20) The survey started to ask about the expected nominal wage from 2017 wave, and thus the sample period is only 2017 and 2018 in this estimation.

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