Modeling heterogeneous inflation expectations: empirical evidence from demographic data?☆

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ABSTRACT

This study proposes the Idiosyncratic Adaptive Expectation model based on decision theory to explain how agents incorporate information about the past to form their inflation expectations. The empirical results suggest that both inflation perception and past actual inflation have significant effects on the formation of inflation expectations, and the Idiosyncratic Adaptive Expectation model is valid in capturing the dynamics of inflation expectations. Investigations of demographic groups provide robust supportive evidence for this novel model. The results suggest that agents are more concerned about inflation perception, which is less costly to understand, than about actual inflation, which entails higher costs. Furthermore, the Granger causality test reveals that more heterogeneous inflation perceptions cause statistically higher heterogeneity in inflation expectations. Compared with rational expectation, adaptive expectation, static expectation and idiosyncratic static expectation models, the Idiosyncratic Adaptive Expectation model is better at capturing inflation expectations empirically. The results have implications for macroeconomic modeling, stressing the significance of perceived and expected inflation.

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1. Introduction

The self-fulfilling feature of expectation implies that well-anchored inflation expectations are essential for price stability and economic development; thus, expectations have become pivotal in modern macroeconomic theory (Majfar and Žakelj, 2014). The theoretical role of inflation expectation formation is evident in the Phillips curve relationship, which has played a central role in applied macroeconomics in recent decades (Rudd and Whelan, 2007). If inflation expectations are adaptive, an impulse in inflation affects the unemployment rate (Friedman, 1968), if inflation expectations are rational, the effects of inflation expectations on unemployment vanish (Lucas, 1972; Sargent, 1973). Consequently, the theoretical implications of the Phillips curve and implementing monetary policy depend on the formation of inflation expectations.

Many theoretical models concerning the expectation formation process suggest that informational frictions and the heterogeneity of expectations are important. However, there is no consensus on how household inflation expectations are formed (see Bernanke, 2007; Bachmann et al., 2015; Coibion and Gorodnichenko, 2015), and the heterogeneity of inflation expectations is difficult to capture empirically. Rational inattention theory, which argues that agents partly incorporate information because of high cost, and the explanation that agents learn from the information derived from their personal perception about inflation are widely accepted in investigations of inflation expectation heterogeneity (de Bruin et al., 2011; Malmendier and Nagel, 2015; Coibion and Gorodnichenko, 2015).

Inflation expectations are generally captured through surveys. Little research has been conducted on the dynamics of inflation expectations from a demographic point of view. According to the decision-theoretic models of perceptual choice that describe how probable and present information should be combined to make optimal choices (Summerfield and de Lange, 2014), this paper proposes a novel model, the Idiosyncratic Adaptive Expectation (IAE) model, to capture the formation of inflation expectations. We present empirical evidence using demographic
data to disentangle the roles of inflation perception and rational inattention in the formation of inflation expectations. By comparing the IAE model with four commonly used inflation expectation formation models, we document that the IAE model performs better at capturing the formation of inflation expectations, followed by the adaptive expectations model. The rational expectations model is the least preferred model. This finding has significant implications for macro modeling, indicating that rational expectation might be inappropriate in capturing households’ inflation expectations and therefore induces misleading conclusions of macroeconomic models, particularly the expectations-Augmented Phillips curve. Moreover, our model considers both rational inattention and heterogeneous personal experience, making the model valid in describing the heterogeneity in demographic inflation expectations.

This study proceeds as follows. Section 2 is a literature review. Section 3 proposes a novel model in capturing the formation of inflation expectations. Section 4 proceeds a preliminary look at the data. Section 5 presents the empirical results and compares the novel model with some other commonly used inflation expectation formation models. Section 6 concludes.

2. Literature review

Various models that describe how agents form inflation expectations have been proposed. The most influential such model is the rational expectations model (RE, Muth, 1961), which is viewed as the standard assumption in most contemporary macroeconomic models of actual inflation (Gali and Gertler, 1999; Rudd and Whelan, 2007). Using household survey data, a large body of literature tests the RE hypothesis, with ambiguous conclusions. Whereas Forsells and Kenny (2004) and Mankiw et al. (2003) reject the RE hypothesis by testing U.S. and Eurozone household survey data, it is suggested that approximately 40% of individuals form expectations consistent with rationality (Pfajfar and Žakelj, 2014), and the RE is supported by the empirical study of Liu and Minford (2014). The rational inflation expectation is embedded in the New Keynesian Phillips curve (NKPC). Whereas Abbas and Sgro (2011), Bloch (2012), and Lee and Yoon (2016) support the NKPC empirically using the RE, Mazumder (2011) and Malikane (2014) cast serious doubt on the empirical viability of the model.

Two other commonly adopted expectation formation models are the static expectation (SE) and adaptive expectation (AE) models. The SE model assumes that the expected inflation equals the latest actual inflation, indicating that the inflation expectations are homogeneous, and the information sets across the agents are the same. The SE often serves as a benchmark in empirical studies (Mehra, 2002) and is employed in the hybrid New Keynesian Phillips curve which has been demonstrated to be effective at capturing the dynamics of the actual inflation in certain literature (Gali and Gertler, 1999). By illustrating the validity of the hybrid NKPC, Henzel and Wollmershäuser (2008) and Xu et al. (2015) tend to support the SE rather than the RE. Similar evidence proving the hybrid NKPC is provided in Narayan et al. (2009), Narayan and Narayan (2010, 2013), and Scharnagl and Stapf (2015). However, the hybrid NKPC faces some criticism (Rudd and Whelan, 2005; Fair, 2008), and the assumption of backward-looking behavior is unappealing theoretically (Dupor et al., 2010). The AE model assumes that the expected inflation is the weighted average of the past inflation expectation and the current actual inflation. With the development of the expectations-Augmented Phillips curve and the accelerationist hypothesis, the AE is widely adopted in empirical and experimental studies. Nevertheless, only actual inflation is viewed as the information used to form inflation expectations, making the AE less attractive in explaining heterogeneity in inflation expectations.

Although the above models are widely used in theoretical and empirical investigations, the information sets used to form inflation expectations are assumed to be the same, and only homogeneous inflation expectations are generated from the models, which contradicts most current investigations. Bryan and Venkatu (2001) illustrate that female, single, nonwhite, less educated, low-income, and young and old agents have significantly higher inflation expectations. Given the difference in income and marriage, females still tend to report higher inflation expectations than males. In investigating the U.S., de Bruin et al. (2010) find that whereas female, older, and single agents tend to report higher expectations, better-educated, low-income, and white agents have lower expectations. Armantier et al. (2015) conclude that female, lower income, and less educated agents tend to possess lower numeracy and financial literacy and are more likely to provide higher and more volatile inflation expectations. Similar conclusions are obtained by Palmqvist and Stroemberg (2004).

The above investigations demonstrate that demographic characteristics have a direct effect on agents’ inflation expectations. Furthermore, the effects of demographic characteristics on the accuracy of inflation expectations are demonstrated in a vast body of literature. For example, higher expectation errors are demonstrated for young individuals, females, low-income agents, low-skilled workers, agents with a non-European background, and respondents from rural areas (Leung, 2009). Using qualitative and quantitative survey data for the U.S., Souleles (2004) reports robust results that show that the elderly, females, blacks, less educated people, low-income people, and agents with a growing number of children have larger forecast errors. Similar conclusions are obtained by Pfajfar (2013), showing that less educated agents have higher forecast errors. Studies on financial literacy (Lusardi and Mitchell, 2008; de Bruin et al., 2010) also provide evidence that demographic characteristics affect the accuracy and level of inflation expectations.

Consumer surveys indicate that household inflation expectations are significantly heterogeneous and are affected by demographic characteristics (Ranyard et al., 2008; Armantier et al., 2013). Three main explanations for the heterogeneity in inflation expectations are empirically and theoretically discussed in the literature. Some authors attribute it to the difference in information sets. Mankiw and Reis (2002) propose a sticky information model in which the information regarding macroeconomic conditions diffuses slowly among firms. The slow spread of information is caused by the costs of the acquisition of information or optimization and induces different information sets in agents, which generate heterogeneous inflation expectations. The model is further investigated empirically in Mankiw et al. (2003) to test whether it is capable of predicting the heterogeneity observed in the Michigan Survey. Significant differences in information update speeds are illustrated in their empirical research, indicating that the heterogeneity between household and professional inflation expectations could be explained by the heterogeneous information sets. An epidemic model proposed by Carroll (2003) assumes that consumers form expectations based on professional forecasts, and information about professional forecasts diffuses slowly. Therefore, the epidemic model is viewed as the microfoundations for the sticky information model in Mankiw and Reis (2002). Although the information stickiness in the formation of inflation expectation is widely illustrated (Carroll, 2003; Doepke et al., 2008), only professional forecasts are viewed as the information source of forming inflation expectations.

Other authors argue that consumers’ personal experiences (which can be inaccurate and diverse) are used to form inflation expectations (de Bruin et al., 2011; Madeira and Zafar, 2015; Malmendier and Nagel, 2015; Coibion and Gorodnichenko, 2015). Positive correlations between perceived and expected inflation are demonstrated in Ranyard et al. (2008), indicating that inflation perceptions are likely to be an important factor affecting inflation expectations. Furthermore, Palmqvist and Stroemberg (2004) find similar characteristics for perceived and expected inflation, i.e., agents’ inflation perceptions and expectations are more accurate into middle age and then deteriorate when they become elderly, implying the same demographic characteristics for perceived and expected inflation. Moreover, Benford (2008) investigates a survey of attitudes towards inflation and notes that perceived inflation is the most important determinant of inflation.
expectations. Maag (2010) reveals that nearly half of households use the idiosyncratic static expectation (ISE) model to form inflation expectations in which perceived inflation is the sole decisive factor. Cavallo et al. (2014) find that agents’ inflation expectations are strongly affected by both inflation statistics and memories of price changes. The above studies reveal the importance of perceived inflation in forming inflation expectations.

Other authors attribute the heterogeneity in inflation expectations to the heterogeneous information-processing capacity and expectation-formation models. Sims (2003) proposes a rational inattention model based on information theories, according to which agents with a limited information-processing capacity optimally ignore certain macroeconomic data that are costly to obtain. Pfajfar (2013) notes that highly educated agents and those with higher incomes produce significantly lower forecast errors of inflation, and they update information sets more regularly. Demographic factors that are related to heterogeneous inflation expectations, e.g., income, education, and gender, could serve as a proxy for information-processing capabilities (Dohmen et al., 2010; Heckman et al., 2006; Grinblatt et al., 2011).

Still other authors argue that the heterogeneity in inflation expectations is caused by the adoption of expectation-formation models. In empirical studies, Branch (2004, 2007), Pfajfar and Santoro (2010), and Maag (2010) demonstrate that agents forecast inflation by rationally choosing a model that is personally optimal rather than the most accurate model. Lanne et al. (2009) show that agents might partly base their expectations on forward-looking information (the inflation target or trend inflation) or backward-looking information (lagged inflation). More experimental evidence on heterogeneous models is provided by Anufriev and Hommes (2012a, 2012b) and Bao et al. (2012). Pfajfar and Žakelj (2014) argue that switching between different models describes agents’ inflation expectation behavior better than relying on a single forecasting rule. However, according to Branch and MCGough (2008) and Pfajfar and Santoro (2013), switching between different forecasting rules is not optimal from the perspective of utility. The same conclusion obtained by the above investigation is that the heterogeneity of inflation expectations is pervasive and significant for policy making and economic growth.

Although many models have been proposed to capture the formation of inflation expectations, no consensus has been reached about how inflation expectations are formed. The classical RE, SE, and AE models fail to explain the heterogeneity in inflation expectations. Although the sticky information model captures the heterogeneity partly, it cannot explain the heterogeneity generated by demographic characteristics, e.g., socioeconomically more advantaged agents (high-income, older, better educated agents) are likely to form more homogeneous inflation expectations (de Bruin et al., 2010). Rational inattention models solve this problem by suggesting that some information is ignored by agents with certain demographic characteristics (Cavallo et al., 2014). However, memory research finds that, when people make predictions about the future, they will likely incorporate memories about the past, particularly the more extreme ones (Morewedge et al., 2005). Moreover, the memories of price changes are nearly orthogonal to the actual price changes (Madeira and Zafar, 2015). Therefore, both sticky information and rational inattention models ignore the important effect of the memory of past inflation, which has been demonstrated to be significant in the formation of inflation expectations (de Bruin et al., 2011; Malmendier and Nagel, 2015). Although personal inflation perceptions about past inflation are considered in the ISE model (Maag, 2010), the statistics about current economic status, such as the actual inflation, are ignored.

3. Idiosyncratic Adaptive Expectation model

In the formation of inflation expectations, agents are faced with the problem of predicting whether (and by how much) prices will go up. They make optimal choices after considering all available information. According to the decision-theoretic models of perceptual choice (Summerfield and de Lange, 2014), information that is probable (expectations) and present (input) should be combined to make optimal choices. Given one option $U$ (e.g., the price in the following 12 months will go up) over the other $U$ (e.g., the price in the following 12 months will not go up), the relative likelihood of stimulus $x$ (e.g., the price of last month) is adopted to make the decision, which is expressed as the log of the likelihood ratio ($LLR$):

$$LLR = \log \frac{p(x|U)}{p(x|\neg U)}.$$  

If $LLR > 0$, the option $U$ will be chosen, and if $LLR < 0$, the option $U$ will be chosen. According to the Bayesian principle, the $LLR$ engenders a shift as follows, indicating that the $LLR$ becomes the log posterior if the prior belief about the underlying options ($U$ versus $U$) is supplemented.

$$LLR = \log \frac{p(U)}{p(U)} + \log \frac{p(x|U)}{p(x|\neg U)}.$$  

Given that the stimuli arrive one after another, according to the sequential sampling models (Summerfield and de Lange, 2014), the decisions follow the integration of information over time. For example, when expecting the aggregate prices for $t+1$ in $t$ to go up or down, agents can optimize decisions by integrating information over time to $t+1$. Based on the Bayesian principle, the sequential probability ratio test (SPRT) suggests that decisions should be made according to the sum of the log likelihoods of all the stimuli during the period.

$$LLR = \log \frac{p(U)}{p(U)} + \log \frac{p(x|U)}{p(x|\neg U)} + \ldots \log \frac{p(x_t|U)}{p(x_t|\neg U)}.$$  

The SPRT can be approximated by the drift-diffusion model (Ratcliff and McKoon, 2008), in which decisions are based on the accumulation of stimulus $I$ and a zero-mean Gaussian disturbing term.

$$DV_t = DV_{t-1} + \beta I_t + N(0, \sigma^2)$$  

where $\beta$ is the multiplicative drift parameter, representing the gain of stimulus, and $DV$ is the decision variable.

In forecasting prices, agents combine all information that is probable and present to make optimal choices. Therefore,

$$R_{t+12} = R_{t+12} + \alpha I_t - 12 - e_t = e_t \sim (0, \sigma^2)$$  

$$F_{t+12} = F_{t+12} + \sigma I_t - 12 + e_t = e_t \sim (0, \sigma^2)$$  

where $R_{t+12}$ and $F_{t+12}$ denote the proportion of respondents expecting the prices of the following 12 months to increase and decrease, respectively, indicating that the proportion is affected by the past proportion and stimulus. According to the net balance statistic, which is commonly used in the economic sentiment survey analysis (Carroll, 2003), the qualitative survey results of inflation expectations can be quantified by the following model:

$$n_{t+12} = \tau (R_{t+12} - F_{t+12})$$  

where $\tau$ is the parameter to be determined, $n_{t+12}$ denotes the inflation expectation for the following 12 months. According to
Eqs. (5) and (6),
\[ n_{t+1}^\pi = n_{t+1}^\pi_{t+1} + \beta u_{t+1} + \varepsilon_t \]

where \( l \) is the stimulus accepted by agents in the formation of inflation expectations. According to Cavallo et al. (2014), agents form inflation expectations using their memories of the past price changes and inflation statistics. More evidence is provided by de Bruin et al. (2011), Madeira and Zafar (2015), Malmendier and Nagel (2015), and Cobbin and Gorton (2015) that the inflation expectation is affected by personal inflation perception. As a consequence, we assume that the stimuli contain the inflation perception \( n_{t+1}^\pi \), and the most recent inflation statistics \( n_{t-1} \). According to the Bayesian principle and the SPRT,

\[ I_{t-12} = \rho n_{t-12} + (1-\rho)n_{t-12}^\pi - \varepsilon_t \]

\[ n_{t+1}^\pi = n_{t+1}^\pi_{t+1} + \beta n_{t+1}^\pi_{t+1} + \gamma (n_{t-1} - n^\pi_{t-12}) + \varepsilon_t \]

where \( \gamma = \beta \rho \), and \( n_{t-12}^\pi \) denotes the inflation perception between \( t - 12 \) and \( t \), and \( n_{t-12} \) denotes the actual inflation between \( t - 1 \) and \( t \). The expected, perceived, and actual inflation rates are annualized inflation rates. Eq. (10) is called the IAE model because the inflation expectation is still adaptive with the information sets being heterogeneous among agents.

Except for the model we proposed in this paper, four widely used inflation expectation formation models (RE, SE, AE, and ISE) are reported here for the empirical study.

RE: Rational expectation (e.g., Maag, 2010). In the RE model, agents are assumed to fully understand the economic structure and related information, and their inflation expectations are completely rational. The inflation expectation (or forecast) of experts is commonly used as a proxy for rational expectation. Thus, the inflation expectation is given by

\[ n_{t+1}^\pi = \beta_0 n_{t+1} + \varepsilon_t \]

where \( \gamma = \beta \rho \), and \( n_{t+1}^\pi \) denotes the professional forecasts.

SE: Static expectation or naive expectation (e.g., Branch, 2004). Traditional SE assumes that the expected inflation of the next period equals the actual current inflation. In the SE model, agents expect the realization of inflation to continue. Therefore, the inflation expectation is given by

\[ n_{t+1}^\pi = \gamma_0 n_{t+1} + \varepsilon_t \]

AE: Adaptive expectation (e.g., Pflaig and Santoro, 2010). AE considers the previous forecast error, assuming that agents absorb the mistakes of previous expectations to adaptively adjust expectations. The inflation expectation generated by AE is the weighted average of two parts:

\[ n_{t+1}^\pi = \beta_0 n_{t+1} + \gamma_0 (n_{t-1} - n^\pi_{t-1}) + \varepsilon_t \]

ISE: Idiosyncratic static expectation (e.g., Maag, 2010). ISE assumes that the expected inflation equals the respondent’s perceived inflation of the last period. In contrast to SE, given that agents may not know the exact actual inflation, they expect the inflation perceived currently to continue. Thus, ISE is given by

\[ n_{t+1}^\pi = \gamma_0 n_{t+1} + \varepsilon_t \]

Compared to the above models, our model considers both agents’ heterogeneity and heterogeneity. The past actual inflation indicates that agents take into account heterogeneous macroeconomic statistics in expecting the future inflation. The past inflation expectation implies that agents may be backward-looking when deciding on the expectation. The inflation perception allows agents to generate heterogeneous expectations using their personal memories about experiences to form inflation expectations. Consequently, our model considers both rational inattentiveness and personal experience, which are the main explanations for the heterogeneity in inflation expectations given in the literature (Cavallo et al., 2014). SE, AE, and RE are chosen because of their long history and prominence in dynamic macroeconomic studies (Branch, 2004), and ISE is selected because of the importance of perceived inflation in forming inflation expectations (Benford, 2008).

4. Data

The European Commission has investigated consumers’ attitude towards the perceptions and expectations of price on a monthly basis since 1985. In the survey, respondents are asked about how they think consumer prices have developed over the last 12 months. Furthermore, respondents are asked about whether they expect prices in the next 12 months to rise, stay the same, or decline in comparison to the past 12 months. The internationally accepted probability method is adopted to measure quantitative inflation expectations and inflation perceptions over 1992/Oct.-2014/Nov. for which both European households’ expectation and perception are available (Carroll, 2003; Doepke et al., 2008; Maag, 2010). Given that significant heterogeneity in perceived and expected inflation has been widely demonstrated (Benford, 2008), this paper reports the mean heterogeneity measured by an index of qualitative variation (IQV; Maag, 2010) in Table 1. The root mean square errors (RMSE) between expected, perceived, and actual inflation are summarized in Table 1. The raw coded data are available from the European Commission and the European Central Bank.

According to Table 1, the heterogeneities in perceived and expected inflation are significant and distinct among different demographic groups. The mean IQVs in 3rd-quartile and 4th-quartile agents are lower than those in 1st-quartile and 2nd-quartile agents, showing that lower heterogeneities in perceived and expected inflation are associated with high-income agents (the 3rd-quartile and 4th-quartile) more than with other agents. The result indicates that the consistency between inflation expectations and inflation perceptions is higher in high-income agents. The significant heterogeneity shown in low-income agents might be induced by the low capacity to process information (Armanter et al., 2015) and the unstable prices of food, which is the primary component of low-income agents’ consumption basket (Cavallo et al., 2014). Significant differences appear among distinct age groups: the IQVs in the in the age groups of 16–29, 50–64, and 65+ years are statistically higher than those in the 30–49 years age group. The results suggest that younger and older agents have significantly higher heterogeneity than middle-aged participants, in alignment with Bryan and Venkat (2001). The IQV of primary-educated agents is highest, followed by that of secondary-educated agents and agents with higher education, indicating that heterogeneity decreases when the education level is higher. Highly educated agents tend to possess more information and a higher information-processing capacity (Armanter et al., 2015), leading to lower and more accurate inflation expectation and perception. For high-income and high-education agents, the costs of collecting information are likely to be lower, inducing a more homogeneous inflation expectation and perception. Although males and females have almost the same heterogeneity in their inflation expectations, females tend to have lower heterogeneity in their inflation perceptions. The difference could be partly attributed to the fact that females possess lower numeracy and financial literacy (Armanter et al., 2015).

On the other hand, by comparing the accuracy of perceived and expected inflation, we find that all agents are more accurate in perceived inflation. This result might be induced by the fact that the past actual inflation is announced when the survey is conducted. Moreover, the lower RMSE between perceived and expected inflation illustrates that the deviation between perceived and expected inflation is much lower than that between expected and actual inflation, implying that inflation expectations could partly be based on the perceived inflation. The lower RMSE shown in older, highly educated, and male agents suggest that the forecast accuracy increases when agents are more advantaged.

Generally speaking, the preliminary analysis of the data notes that socioeconomically more advantaged agents (high-income, older, better
Expectations are between perceived and actual in each other during 1997. Fig. 1, the perceived and expected in the actual in the relationship between perceived and expected in. The expected and perceived in agree with the AE and SE. However, there are significant deviations between them during 1997–2000, 2003–2007, and 2011–2014 (see the shaded area in Fig. 1), making the stable correlations questionable. The expected and perceived inflation are somewhat less volatile than the actual inflation, particularly the perceived inflation. According to Fig. 1, the perceived and expected inflation are extremely close to each other during 1997–2000 and 2011–2012 when the deviation between expected and actual inflation is significant, showing that the relationship between perceived and expected inflation is closer than that between expected and actual inflation during the periods. The inflation expectations are between perceived and actual inflation most of the time, implying that both inflation perceptions and past actual inflation might have certain effects on inflation expectations.

Agents with different demographic characteristics have heterogeneous inflation expectations and perceptions (Ranyard et al., 2008; Armantier et al., 2013). Moreover, the correlations among actual, perceived and expected inflation are different across demographic groups. Fig. 2 suggests that inflation expectations under different income levels are distinct. For agents with lower income (i.e., 1st-quartile and 2nd-quartile), inflation expectations and perceptions tend to be more volatile, and the correlation between expected and actual inflation are closer than that between expected and perceived inflation. For agents with higher income (i.e., 3rd quartile and 4th quartile), the conclusion is opposite: Expected and perceived inflation appear to have closer relationship than expected and actual inflation. The findings agree with Gamble (2006), in which individuals’ inflation perceptions and expectations are influenced by their personal income. For agents who are younger (16–29 and 30–49) and better educated (further-educated), the correlation between expected and actual inflation is closer than that between expected and perceived inflation. The conclusion is opposite for older (50–64 and 65+) and low-educated (primary and secondary) agents: Expected and perceived inflation have a closer relationship than expected and actual inflation. However, the difference between males and females appears to be less apparent than other demographic characteristics.2

Given that only homogeneous information sources, such as professional forecasts and actual inflation are considered, the differences between ages, income and education levels are unlikely to be explained by the RE, SE, or AE models. However, if inflation perception is one of the information sources adopted by certain agents, the heterogeneity within and between different demographic groups is accountable. The rational inattention model suggests that agents with a limited information-processing capacity optimally ignore certain macroeconomic data that are costly to obtain (Sims, 2003); therefore, agents with different demographic characteristics might ignore inflation statistics that cost more to collect and base their inflation expectation on their personal experience (Malmendier and Nagel, 2015; Cobion and Gorodnichenko, 2015).

5. Empirical results

5.1. Estimation of the Idiosyncratic Adaptive Expectation model

The theoretical implications of the Phillips curve relationship depend on the formation of inflation expectations, making this

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Table 1: Heterogeneity and accuracy of perceived and expected inflation.

<table>
<thead>
<tr>
<th>Demographic characteristics</th>
<th>Mean IQV</th>
<th>RMSE</th>
<th>Expectation-perception</th>
<th>Perception-inflation</th>
<th>Expectation-inflation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Expectation</td>
<td>Perception</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Income</td>
<td>1st-quartile: 0.907</td>
<td>0.892</td>
<td>0.472</td>
<td>0.578</td>
<td>0.653</td>
</tr>
<tr>
<td></td>
<td>2nd-quartile: 0.892</td>
<td>0.888</td>
<td>0.489</td>
<td>0.577</td>
<td>0.662</td>
</tr>
<tr>
<td></td>
<td>3rd-quartile: 0.883</td>
<td>0.887</td>
<td>0.184</td>
<td>0.579</td>
<td>0.663</td>
</tr>
<tr>
<td></td>
<td>4th-quartile: 0.882</td>
<td>0.887</td>
<td>0.207</td>
<td>0.574</td>
<td>0.646</td>
</tr>
<tr>
<td>Age</td>
<td>16–29: 0.894</td>
<td>0.896</td>
<td>0.366</td>
<td>0.567</td>
<td>0.666</td>
</tr>
<tr>
<td></td>
<td>30–49: 0.885</td>
<td>0.890</td>
<td>0.187</td>
<td>0.564</td>
<td>0.659</td>
</tr>
<tr>
<td></td>
<td>50–64: 0.895</td>
<td>0.888</td>
<td>0.462</td>
<td>0.566</td>
<td>0.628</td>
</tr>
<tr>
<td></td>
<td>65+: 0.910</td>
<td>0.892</td>
<td>0.484</td>
<td>0.559</td>
<td>0.638</td>
</tr>
<tr>
<td>Education</td>
<td>Primary: 0.910</td>
<td>0.892</td>
<td>0.614</td>
<td>0.553</td>
<td>0.653</td>
</tr>
<tr>
<td></td>
<td>Secondary: 0.892</td>
<td>0.890</td>
<td>0.499</td>
<td>0.566</td>
<td>0.646</td>
</tr>
<tr>
<td></td>
<td>Further: 0.882</td>
<td>0.884</td>
<td>0.204</td>
<td>0.569</td>
<td>0.651</td>
</tr>
<tr>
<td>Gender</td>
<td>Female: 0.897</td>
<td>0.889</td>
<td>0.570</td>
<td>0.566</td>
<td>0.654</td>
</tr>
<tr>
<td></td>
<td>Male: 0.896</td>
<td>0.894</td>
<td>0.476</td>
<td>0.557</td>
<td>0.638</td>
</tr>
<tr>
<td></td>
<td>Overall: 0.896</td>
<td>0.893</td>
<td>0.482</td>
<td>0.565</td>
<td>0.638</td>
</tr>
</tbody>
</table>

Notes: The IQV quantifies the inflation forecast disagreement of households, $IQV(X) = \frac{1}{K} \sum_{k=1}^{K} p(k) \left(1 - \frac{1}{K} \sum_{j=1}^{K} \frac{1}{j^2} \right),$ where $K = 6$ is the number of categories in the survey question on perceived and expected inflation and $p(k)$ is the fraction of answers in category $k$. The IQV closely traces the actual standard deviation of perceived and expected inflation. The mean IQV is the mean value of the values of IQV from 1992/Oct. to 2014/Nov.

Fig. 1. Expected, perceived, and actual inflation rates.

The shaded area shows significant deviations between expected and actual inflation.

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2 The figures about age, education, and gender are not shown here for the sake of brevity, but are available once requested.
relationship important for central banks and monetary policy (Maag, 2010). However, there is no consensus on how household inflation expectations are formed. Although RE, SE, AE, and ISE models are widely adopted to capture the formation of inflation expectations and have achieved some success (Maag, 2010), they have certain disadvantages, as analyzed above. Therefore, this paper proposes an IAE model that considers the effects of both inflation statistics and inflation perceptions. The comparisons between different inflation expectation formation models are summarized in Tables 2, 3, and 4. Table 2 compares the five models by estimating the full sample estimation, Table 3 compares models before and after the euro cash changeover in 2002, and Table 4 compares the log likelihood values of five models in different demographic groups.

According to Table 2, the five models are effective at capturing the formation of inflation expectations with the significance of corresponding variables. The adjusted R-squared ($R^2$) of the IAE model is much higher than that of the other four models, followed by ISE, AE, SE, and RE, suggesting that the IAE model is better in explaining the dynamics of overall inflation expectations. The log likelihood test is adopted for further comparison. According to the results of the test, the IAE model dominates the AE and ISE at the 1% significance level and the SE at the 5% significance level. The results suggest that the inflation expectation

---

**Table 2**  
Comparison between five inflation expectation-formation models.

<table>
<thead>
<tr>
<th>Dependent variable: $\pi_{t,t+12}$</th>
<th>IAE</th>
<th>AE</th>
<th>ISE</th>
<th>SE</th>
<th>RE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>-0.130</td>
<td>0.162***</td>
<td>0.292</td>
<td>1.169***</td>
<td></td>
</tr>
<tr>
<td>$\pi_{t-1,t+11}$</td>
<td>0.380***</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\pi_{t-1}$</td>
<td>0.666***</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\pi_{t-1}$</td>
<td>0.184***</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\pi_{t-1}$</td>
<td>0.908***</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\pi_{t-1}$</td>
<td>-0.801***</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\pi_{t,t+12}$</td>
<td>0.903</td>
<td>0.895</td>
<td>0.897</td>
<td>0.896</td>
<td>0.977***</td>
</tr>
<tr>
<td>$R^2$</td>
<td>94.418</td>
<td>82.450</td>
<td>75.367</td>
<td>74.535</td>
<td>-24.133</td>
</tr>
<tr>
<td>Log L</td>
<td>262</td>
<td>262</td>
<td>265</td>
<td>265</td>
<td>58</td>
</tr>
<tr>
<td>Forecast accuracy</td>
<td>0.275</td>
<td>0.382</td>
<td>0.455</td>
<td>0.453</td>
<td>0.578</td>
</tr>
</tbody>
</table>

Notes: There are 58 observations in estimating RE because the professional forecasts are surveyed quarterly. Log L denotes the corresponding log likelihood values. The last row summarized the forecast accuracy of five models which is measured by the RMSE.

*** Denotes significance at the 1% level.
is more likely to be formed according to the IAE model than to the other four commonly used models. Because the theoretical implications of the Phillips curve relationship depend on the formation of inflation expectations, it is important to see whether the inflation expectations implied by the model match the real survey expectations. Therefore, we provide the dynamic forecast accuracy of five models for comparison. As shown in Table 2, the RMSE of the IAE model is the lowest, indicating that the model performs best in forecasting the real survey expectations.

The results of full sample estimation suggest that both past and perceived inflation are considered by agents in forming inflation expectations. The positive coefficients show that if the past actual inflation and inflation perception are higher, inflation expectations will be higher. By contrast, the coefficient of the inflation perception is significantly greater than that of the past inflation, indicating that agents tend to learn more from their personal experience than from inflation statistics. The result is consistent with inattention theory, i.e., costlier in-attention in expectation-formation models in demographic characteristics (Palmqvist and Stroemberg, 2004). Consequently, learning from inflation perceptions are inaccurate and diverse for different people (Coibion and Gorodnichenko, 2015) and are affected by demographic statistics (Sims, 2003). In additional to the IAE model before and after the euro cash changeover, the results further suggest that the shock of the euro cash changeover seems to have exerted little effect on the formation of the aggregate European inflation expectations, illustrating the robustness of the IAE model in capturing aggregate inflation expectations.

Given that the IAE model considers the inflation perception that is heterogeneous across different demographic groups, we expect the model to perform better in describing the inflation expectations of demographic groups. The log likelihood values of the IAE model are significantly higher than those of the ISE, AE, and SE models, illustrating the dominance of the IAE model in capturing the aggregate inflation expectations. By adopting the Wald test, we find that the coefficient of the inflation expectation in the IAE model before and after the euro cash changeover has no significant change (F-stat: 2.212, p-value: 13.90%). Analogously, the coefficients of the inflation perception (F-stat: 0.075, p-value: 78.49%) and past inflation (F-stat: 0.199, p-value: 65.60%) remain unchanged after the euro cash changeover. The results further suggest that the shock of the euro cash changeover seems to have exerted little effect on the formation of the aggregate European inflation expectations, illustrating the robustness of the IAE model in capturing aggregate inflation expectations.

Table 3
Comparison between four inflation expectation-formation models before and after the euro cash changeover.

| Log likelihood values of five inflation expectation-formation models in demographic groups. |
|---------------------------------|---|---|---|---|---|
| IAE | AE | ISE | SE | RE |
| Income 1st-quartile | 49.081 | 45.000 | 34.879 | 34.320 | –13.465 |
| 2nd-quartile | 50.145 | 42.336 | 31.395 | 35.102 | –13.137 |
| 3rd-quartile | 334.728 | 323.001 | 311.931 | 314.429 | 12.497 |
| 4th-quartile | 315.632 | 297.725 | 295.311 | 287.014 | 8.806 |
| Age 16–29 | 302.056 | 295.079 | 283.276 | 285.514 | 20.010 |
| 30–49 | 360.762 | 341.899 | 334.069 | 332.853 | 13.768 |
| 50–64 | 44.585 | 36.125 | 25.147 | 25.878 | –31.536 |
| 65+ | 48.461 | 43.661 | 31.605 | 28.806 | 26.764 |
| Education Primary | 60.103 | 54.249 | 45.186 | 49.267 | 18.577 |
| Secondary | 59.530 | 59.153 | 42.724 | 43.749 | 25.232 |
| Further | 319.373 | 310.598 | 294.473 | 287.779 | 14.372 |
| Gender Female | 77.438 | 71.059 | 62.350 | 65.711 | –22.619 |
| Male | 65.546 | 52.046 | 43.118 | 42.198 | –24.133 |

Notes: Considering the weakness of the RE model in capturing the inflation expectations and the limitation of sample size, this table does not consider the RE model. Log L denotes the corresponding log likelihood values. ** Denotes significance at the 1% level. * Denotes significance at the 5% level. * Denotes significance at the 10% level.
According to Table 4, the likelihood value of the IAE model is greater than that of the AE model at the 1% significance level (except for secondary-educated agents), showing that inflation perception is an important information source for agents with various demographic characteristics. Similarly, the conclusion that past actual and expected inflation validate in the formation of inflation expectations can be obtained by comparing the IAE and ISE models. Given that both the heterogeneity and homogeneity of agents are considered, the IAE model can capture not only the aggregate inflation expectations but also the demographic inflation expectations.

The estimations of different demographic agents are summarized in Table 5. By comparing the results of various groups, we find some evidence for the heterogeneity of inflation expectations and corresponding reasons. Low-income agents, i.e., the 1st and 2nd quartiles, are more affected by personal inflation perceptions and past actual inflation than are high-income agents. Furthermore, the coefficients of inflation perceptions are significantly greater than those of actual inflation, illustrating that regardless of the income level, agents learn more from perceived inflation than from actual inflation. These results are in line with the rational inattention model (Sims, 2003; Veldkamp, 2011; Cavallo et al., 2014), predicting that agents will adopt personal experience, which is less costly to obtain than inflation statistics, to form inflation expectations. The coefficients of past inflation expectation are significant for agents with different incomes, implying significant inflation expectation persistence. Similarly, agents at different ages have significant inflation expectation persistence with the coefficients of past inflation expectation being significant. The coefficients of past and perceived inflation and past inflation expectations become larger as the age increases, indicating that agents learn more from information related to personal experience and inflation statistics. Older agents (50–64 and 65+) are more affected by personal experience than younger agents. Low-educated agents pay little attention to personal inflation perception and have significantly higher inflation expectation persistence than higher-educated agents. Agents who are better educated tend to accommodate all available information to form inflation expectations. Although females and males show little difference in learning from actual inflation, males are more likely to be affected by perceived inflation. Agents with different genders have comparatively the same persistence in inflation expectations. By comparing the coefficients of inflation perceptions and past inflation, we find that the interaction between perceived and expected inflation is stronger than that between actual and expected inflation, which reconcile to the findings of Dräger (2015). The results suggest that rational inattention is significant among all demographic groups.

Cavallo et al. (2014) provides evidence that suggests that in the formation of inflation expectations, both memories of the price changes of products agents purchase and inflation statistics are of concern. Although the actual price changes these products experienced are nearly orthogonal to agents’ personal memories, agents are more concerned with memories than statistics. Similarly, our model suggests the robust dominance of inflation perceptions over inflation statistics among different demographic groups. The results indicate that agents are more affected by information that is less costly to understand (inflation expectation) than by information that costs more to comprehend (inflation statistics), which is consistent with the rational inattention theory (Sims, 2003).

5.2. Granger-causality test

Statistical analysis indicates that the past actual inflation and inflation perceptions for the past 12 months are likely to affect the inflation expectation for the coming 12 months. If inflation expectations are based on the information set of inflation perception and past actual inflation, inflation perception and past actual inflation should be the causality of inflation expectation. With regard to the direction of causality, many investigations provide evidence that inflation expectations are based on the perception of past inflation (Benford, 2008; Dräger, 2015; Maag, 2010). However, there is some empirical evidence of causality running from inflation expectations to perceptions. For example, in the experimental study conducted by Traut-Mattausch et al. (2004), the perceptions are significantly biased towards increasing price, which could not be explained by the memory biases or inaccurate recall. The authors attribute the findings to the so-called ‘expectancy confirmation hypothesis’, arguing that agents that expect prices to rise will perceive price increases. Fluch and Stix (2005) and Hofmann et al. (2007) also point to the possible direction of causality from expectations to perceptions.

To test the statistical causality relation between expected, perceived, and actual inflation, we adopt the Granger-causality test. According to Table 6, there is a significant Granger-causal relationship between inflation expectation and inflation perception in the estimation of the full sample, indicating that the historical inflation perception of agents helps explain the current inflation expectation. Moreover, the past actual inflation statistically explains the overall inflation expectation, and no statistical causality is found from expected inflation to perceived inflation. Given that the actual inflation affects the macro-economy in various aspects, e.g., consumption and investment (Mallick and Mohsin, 2007, 2009), and is influenced by many factors, e.g., monetary policy (Mallick, 2005; Mallick and Sousa, 2013a, 2013b), the implementation of monetary policies that help maintain stable inflation benefit the anchoring of inflation expectations (Zhang, 2011). The results provide evidence of robustness for the IAE model.

### Table 5

Demographic estimation results of the IAE model.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Income 1st-quartile</th>
<th>Income 2nd-quartile</th>
<th>Income 3rd-quartile</th>
<th>Income 4th-quartile</th>
<th>Age 16–29</th>
<th>Age 30–49</th>
<th>Age 50–64</th>
<th>Age 65+</th>
<th>Education Primary</th>
<th>Education Secondary</th>
<th>Education Further</th>
<th>Gender Female</th>
<th>Gender Male</th>
<th>All</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>0.025</td>
<td>0.112</td>
<td>0.484</td>
<td>0.496</td>
<td>0.899</td>
<td>0.502</td>
<td>−0.199</td>
<td>−0.226</td>
<td>0.348</td>
<td>0.478</td>
<td>0.503</td>
<td>0.491</td>
<td>−0.256</td>
<td>−0.130</td>
</tr>
<tr>
<td>$n_{T−1,1;11}$</td>
<td>0.410***</td>
<td>0.346***</td>
<td>0.436***</td>
<td>0.394***</td>
<td>0.362***</td>
<td>0.403***</td>
<td>0.416***</td>
<td>0.431***</td>
<td>0.835</td>
<td>0.235**</td>
<td>0.386***</td>
<td>0.407***</td>
<td>0.369***</td>
<td>0.386***</td>
</tr>
<tr>
<td>$n_{T−1;1}$</td>
<td>0.568***</td>
<td>0.582**</td>
<td>0.314***</td>
<td>0.352</td>
<td>0.171***</td>
<td>0.338***</td>
<td>0.678**</td>
<td>0.675**</td>
<td>0.025</td>
<td>0.496**</td>
<td>0.354**</td>
<td>0.321**</td>
<td>0.751**</td>
<td>0.666**</td>
</tr>
<tr>
<td>$n_{T−1,1}−n_{T−1;1}$</td>
<td>0.144***</td>
<td>0.224***</td>
<td>0.059***</td>
<td>0.071***</td>
<td>0.084***</td>
<td>0.073***</td>
<td>0.180***</td>
<td>0.123***</td>
<td>0.129**</td>
<td>0.292***</td>
<td>0.073***</td>
<td>0.189***</td>
<td>0.190***</td>
<td>0.184***</td>
</tr>
<tr>
<td>$R^2$</td>
<td>0.856</td>
<td>0.868</td>
<td>0.901</td>
<td>0.909</td>
<td>0.884</td>
<td>0.526</td>
<td>0.861</td>
<td>0.863</td>
<td>0.876</td>
<td>0.880</td>
<td>0.905</td>
<td>0.883</td>
<td>0.887</td>
<td>0.903</td>
</tr>
<tr>
<td>Log L</td>
<td>49.081</td>
<td>50.145</td>
<td>334.728</td>
<td>315.632</td>
<td>302.056</td>
<td>360.762</td>
<td>44.585</td>
<td>48.461</td>
<td>60.103</td>
<td>59.530</td>
<td>319.373</td>
<td>77.418</td>
<td>65.546</td>
<td>94.418</td>
</tr>
</tbody>
</table>

Notes: Log L denotes the corresponding log likelihood values.

*** Denotes significance at the 1% level.

** Denotes significance at the 5% level.
Further estimation using demographic group data finds that although the causality from inflation expectations to perceptions is demonstrated in some demographic groups, i.e., agents who are aged 30–49 years, aged older than 65 years, are in the 3rd income level, and are primary educated, more evidence are provided on the causality from perceptions to expectations. The result can be partly explained by the investigation of Ranyard et al. (2008), specifying that both perceptions to expectations. The result can be partly explained by the investigation of Ranyard et al. (2008), specifying that both perceptions to expectations and expectation are affected by media reports and actual inflation. Inflation expectation affects inflation expectations via agents’ spending behavior, and expectations feed back into inflation perception through saving, spending and investment decisions which influence actual inflation. Similarly, the casual relationships between inflation expectations and past actual inflation are robust. The Granger-causality test provides evidence for the IAE model assuming that agents’ inflation perception and past actual inflation induce inflation expectations.

5.3. Heterogeneities in inflation expectation and inflation perception

If we assume that agents learn from their inflation perceptions, we should expect that more heterogeneous inflation perceptions should induce higher heterogeneity in inflation expectations. Fig. 3 plots the heterogeneities in inflation expectations and inflation perceptions. Unsurprisingly, the heterogeneity in inflation perceptions is closely related to that in inflation perception. Note that the inflation perceptions fluctuate more than inflation expectations, and the correlation between heterogeneities in expected and perceived inflation is closer when the inflation was very high (see the shaded area in Fig. 3). For example, from October 1992 to August 1996, 2000 to 2006, October 2007 to November 2008, and October 2010 to January 2013, when the actual inflation was higher than 2.0, the heterogeneity in expected inflation has the same tendency as that in perceived inflation. Although a high heterogeneity in inflation expectation usually coincides with more heterogeneous inflation perceptions, the reverse is generally not true. There can be high heterogeneity in inflation expectations and low heterogeneity in inflation perceptions and vice versa. Examples of this phenomenon can be found in 1998–2000 and 2009–2010. According to Eqs. (5), (6), and the definition of IQVe, the heterogeneities in inflation expectations and inflation expectations are not linearly correlated. The nonparametric tests of the Kendall method (τ-stat: 0.093, p-value: 0.019) and the Spearman rank correlation test (γ-stat: 0.134, p-value: 0.029) are adopted to investigate the nonlinear relationship, showing that the heterogeneities in perceived and expected inflation are statistically correlated with each other. The results suggest that higher heterogeneity in inflation expectations is generally associated with more heterogeneous inflation perceptions.

The finding that inflation expectations are more heterogeneous when there is higher heterogeneity in inflation perceptions is an indirect implication of the IAE model under the assumption that agents learn from their personal experiences. The proposition that the heterogeneity in inflation perception induces heterogeneous inflation expectations can also be tested directly. Table 6 presents the Granger test results of the statistical causality between heterogeneities in perceived and expected inflation. The F-test indicates that heterogeneous inflation perceptions causes the heterogeneity in inflation expectations statistically at the 1% level. Nevertheless, there is no causality relationship that goes from the heterogeneity in expected inflation to that in perceived inflation, indicating that the lagged heterogeneity in inflation perception significantly affects the inflation expectation; nonetheless, the reverse causality link is not statistically significant. This finding confirms that although reverse causality might be present, the dominating channel is the effect of inflation perception on inflation expectation and there is no measurable feedback effect of the heterogeneity in inflation expectations.

Heterogeneity is important because it implies that the central bank and monetary policy are imperfectly credible, inducing volatile long-term inflation expectations and actual inflation (Kabundi et al., 2015). Trying to manage inflation expectations requires an understanding of the process of inflation expectation formation. The conclusion that heterogeneity in inflation perception leads to heterogeneous inflation expectations suggests that for the management of inflation expectations, more focus should be put on the inflation perception. Media reports are found to exert influence on both inflation perceptions and their

![Fig. 3. Heterogeneity in inflation expectation and inflation perception.](image-url)
dispersion, triggering more heterogeneous inflation expectations and dynamic economy (Lamla and Maag, 2009). Therefore, communication and policy based on heterogeneous agents help manage inflation expectations (Reid, 2015), and better communicated monetary policies will decrease the bias of media reports and perceptions, which will benefit the anchoring of inflation expectations (Dräger, 2015).

6. Conclusions

This paper proposes an IAE model based on decision theory to explain how agents incorporate information about the past to form their inflation expectations. Our model assumes that agents learn from their past inflation perception and actual inflation to form their expectations about future inflation (Cavallo et al., 2014). The empirical results suggest that both inflation perception and past actual inflation cause inflation expectation statistically, and higher heterogeneity in inflation perception will induce more heterogeneous inflation expectations. We also find that agents are more concerned about inflation perception, which is less costly to understand, than actual inflation, which is costlier to understand (except for the primarily educated agents). This finding is consistent with the rational inattention theory ( Sims, 2003; Cavallo et al., 2014). The result helps explain the heterogeneity of inflation expectations considering that inflation perceptions are significantly heterogeneous. Furthermore, there is significant inflation expectation persistence across all demographic agents, implying that well-anchored inflation expectations benefit the stability of the economy and poorly anchored inflation expectations will damage the economy. By comparing the IAE with four commonly used inflation expectation-formation models, we document the dominance of the IAE model over the other four models. The findings in this paper shed light on macroeconomic modeling, especially the Phillips curve, which argues for rational expectations considering that inflation expectations are segmented and poorly anchored in heterogeneous economies (Lamla and Maag, 2009). Therefore, communication and behavior: do survey respondents act on their beliefs? Int. Econ. Rev. 56 (2), 536–557.

References


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