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Consumer and Professional Inflation Expectations – Properties and Mutual Dependencies

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Abstract

Inflation expectations are a crucial variable for central banks. However, empirically examining their properties is challenging. This paper juxtaposes the properties of consumer and professional expectations. It also assesses the degree of forward- and backward-lookingness and the information content of expectations. We apply entropy-based measures (common information and mutual common information) to capture nonlinear dependencies and dynamic time warping to account for different lags in the relationships. The study covers 12 inflation-targeting economies from the European region. The results suggest that in most countries, professionals are more forward-looking, and consumers follow professionals. Both groups of economic agents present expectations that are aligned in terms of information content. However, cross-country differences occur. These results imply that, from the central bank's point of view, communication and practices designed to shape expectations, even if understood mostly by specialists, are effective also for consumers. The novelty of this study

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lies in its use of alternative methods to tackle the formation and dependencies between heterogeneous expectations. This avoids the drawbacks of a standard approach and allows broader conclusions to be drawn.

Keywords: inflation expectation, mutual information, dynamic time warping

JEL: C82, D84, E31

Introduction

Empirical studies have shown that expectations vary across different groups of economic agents, and they display different properties (Gerberding 2001; Łyziak and Mackiewicz-Łyziak 2014; Łyziak and Sheng 2023). Even within the same group of economic agents, there is a dispersion of expectations due to different cognitive abilities (D'Acunto et al. 2019), personality traits (Abildgren and Kuchler 2021) or economic characteristics (Zhao 2022). Macromodels assume homogeneity of expectations, although this assumption does not hold when expectations are studied empirically. The question of whose expectations matter more for the evolution of inflation remains unanswered. Coibion and Gorodnichenko (2015) found that consumer expectations are more important for the economy's price-setting patterns than those of specialists. When expectations are disaggregated according to socioeconomic or demographic characteristics, high-income, college-educated, male, and working people play a larger role in inflation dynamics than other consumers or professional forecasters' expectations (Binder 2015).

This study highlights the limitations of current methods for assessing expectation properties. These methods often ignore time series characteristics like non-stationarity and non-linearity of dependencies when estimating regressions. Additionally, they assume a constant lag structure of inflation and inflation expectations. We address these issues in Section 2. Standard econometric methods used to measure forward-lookingness, backward-lookingness, and co-movements of expectations suffer from practical application problems. The residuals from the estimated regressions rarely meet the assumptions. To overcome these limitations, we apply a novel methodology based on dynamic time warping distance using distance measures rather than regression estimates and common information measures to capture linear and nonlinear dependencies. The proposed method offers deeper insights into the dependencies between time series studied than standard methods by providing a more comprehensive analysis.

This study investigates the relationship between consumer and professional expectations of inflation. We analyse the co-movements and information content of these expectations, along with their forward- and backward-looking nature. Utilizing a unique data set on consumer and professional expectations, we also examine how inflation expectations co-move. This study addresses the following questions:

Q1: Do the inflation expectations of professionals carry the same information content as consumer expectations?

Q2: Is the common information between consumer and professional expectations the effect of a transfer of inflation information?

Q3: Are consumers more backward- or forward-looking?

Q4: Are professionals more backward- or forward-looking?

The study employs a novel method utilizing entropy-based and distance measures. To assess the degree of backward- or forward-lookingness of expectations, we use the dynamic time warping (DTW) algorithm, incorporating the windowing technique proposed by Rutkowska and Szyszko (2022). Additionally, to assess information carried by the inflation expectations of professionals and consumers, we use mutual information that can be interpreted as the "amount of information" obtained about one random variable by observing another.

The sample includes Albania, Czechia, Hungary, Kazakhstan, Norway, Poland, Romania, Russia, Serbia, Sweden, Turkey and the UK. We selected small open economies from the Eurasia region because they conduct independent monetary policy, and their central banks implement inflation targeting (IT) as a monetary policy framework. This strategy focuses on managing expectations. Thus, the issue of expectation formation and co-movements is crucial from a central bank perspective. The research period varies depending on the year each country adopted IT adoption and ends for all countries in June 2019.

Professional expectations are measured using Consensus Forecasts from Consensus Economics data, which are transformed into fixed-horizon forecasts. Consumer expectations for European Union Member States and Albania (complemented by central banks' data before May 2016), Serbia, Turkey, and the UK are derived from Business and Consumer Surveys. For Kazakhstan, Norway and Russia, we use survey results published by their national central banks.

DTW is often used to overcome distortions by aligning and classifying time series and helping to classify it (El Amouri et al. 2022). It has attracted significant research attention in economics because it imposes no specific conditions on time series or lags. DTW has been used to detect recessions (Raihan 2017), the clustering of business cycles (Franses and Wiemann 2020), and pattern recognition in stock markets (Han et al. 2020). The work most closely related to ours is Rutkowska and Szyszko's (2022) first attempt to analyse the forward- and backward-lookingness of consumer expectations for seven small open economies: Croatia, Czechia, Hungary, Poland, Romania, Sweden, and the UK. Our paper builds on this previous study in three key ways:

1. We test the properties of two groups of economic agents (consumers and professionals).
2. We expand the sample to include 12 economies that have implemented IT.
3. We consider the co-movement of consumer and professional expectations.

The second method applied – mutual information and conditional mutual information – allows us to determine how much information can be obtained about the expectations of one group of agents by observing another group. This methodology has already been used to find information flow between economic and financial variables, including asset prices (Lahmiri and Bekiros 2020; Będowska-Sójka, Kliber, and Rutkowska 2021; Ferreira and Morais 2023).

The remainder of this paper proceeds as follows: The next section briefly reviews standard methods to assess expectations properties, and the third section describes the methods and data used in the study. The fourth section presents the results. The paper ends with conclusions.

The standard method to assess properties of expectations

This paper focuses on the forward- and backward-lookingness of inflation expectations. These characteristics describe the degree to which inflation expectations are shaped by past inflation trends (backward-lookingness, BL) or future inflation trends (forward-lookingness, FL). When economic agents forecast inflation, they may consider only past inflation (BL) or base their forecasts on numerous forward-looking factors (FL).

Pure forward-looking behaviour is one of the characteristics of rational expectations, as presented by Muth (1961) and introduced to macroeconomic models by Lucas Jr. (1972; 1976)[1]. However, neither rationality of expectations nor pure forward-lookingness hold empirically. Thus, expectations regarding their degree of FL or BL (hybrid) are studied.

The standard procedure to assess the degree of BL and FL involves identifying the forward-looking component of expectations and the backward-looking component. The backward-looking component refers to the adaptive expectations hypothesis[2]

1 Rational expectations exhibit several features, unbiassedness and orthogonality being the most important. We refrain from their detailed description in this paper, as our intentions are mostly about a novel method.

2 Assumes that past inflation, past expectations presented and expectation errors drive inflation.

(Eq. 1) or static expectations[3] (Eq. 2eq:2). Two specifications of the hybrid nature of expectations are presented below.

$$\pi^{e}_{t+12|t} = \alpha_1 + \alpha_2 \pi_{t+12} + \\ (1-\alpha_2)\left[\pi^{e}_{t-2|t-14} + \alpha_3\left(\pi^{e}_{t-2|t-14} - \pi_{t-2}\right)\right] + \varepsilon_t, \tag{1}$$

$$\pi^{e}_{t+12|t} = \alpha_1 + \alpha_2 \pi_{t+12} + (1-\alpha_2)\pi_{t-2} + \varepsilon_t, \tag{2}$$

where:

$\pi^{e}_{t+12|t}$ is the expected inflation rate at time $t+12$ formed at time t,

π_{t+12} is the actual inflation at $t+12$ (analogous to the meaning of other subindices), and

ε_t is the white noise error.

For both models, the expectations are entirely forward-looking if $\alpha_1 = 0$ and $\alpha_2 = 1$.

Equations 1 and 2 differ in terms of how they understand a non-forward-looking component of expectations. The second model (Eq. 2) – the static specification – is more intuitive and aligned with the method applied in this study. It simply assesses the degree to which expectations incorporate past inflation (BL) and future inflation (FL). Both methods should be applied to stationary time series. However, in practice, neither inflation nor expectations are stationary, especially when in emerging or transition economies. Despite this, most studies do not report stationarity or unit root tests. It is often assumed that time series are stationary over the medium and long term, as forming unbiased expectations in a nonstationary environment would, in many circumstances, be an implausibly demanding task (Evans and Gulamani 1984).

The estimator is a separate element on which the results depend; it is somewhat arbitrary and must be selected before analysis. The endogeneity problem makes ordinary least squares (OLS) estimations inconsistent. Therefore, a common solution is the regression of instrumental variables (two-stage least squares (2SLS) estimation). However, this choice is associated with inaccuracy due to large standard errors, bias when the sample size is small, and bias in large samples if one of the assumptions is only slightly violated (Martens et al. 2006). The issue of weak instruments and their consequences has been extensively discussed in the literature (Staiger and Stock 1994; Stock and Wright 2000; Hahn, Hausman, and Kuersteiner 2004).

3 Assume that past inflation drives expectations.

The standard specification imposes a fixed structure of lags, as reflected in the subindices of our equations. The $T+12$-month horizon of expectations relates to the survey questions where consumers were asked about their price level estimates for the next 12 months. Their expectations are juxtaposed with actual inflation over a one-year horizon and past inflation. Past inflation from two months before the survey is considered $(t-2)$ because this is the most recent inflation available for consumers due to the survey schedule and macroeconomic data publication calendar. For instance, if we use the June survey as an example, the respondents could be aware of April inflation (published at the end of May). Moreover, consumers need time to process economic information. Thus, a two-month lag is the shortest period that seems justified.

When examining the alignment of disagreement between different groups of economic agents, the traditional approach offers limited procedures. One of them is to run standard Granger causality tests, as presented by Łyziak (2013). These tests are often incorporated into theoretical models, such as Carroll's (2002) epidemiological theory of expectations, to assess the dependencies between the expectations of different groups of economic agents. The epidemiological theory of expectations posits that consumers form their expectations based on media news spread by professionals. Empirical testing of this model often reveals that consumers are influenced by professionals. Specifically, Granger causality from the professional forecasts (presented in the media) to consumer expectations exists, but the reverse is not true. To identify the long-run relationship between the expectations of different groups of economic agents, vector error correction models are estimated and impulse responses are tested. Drager (2015) applied a similar procedure to identify dependencies between consumer and professional expectations.

An alternative, theory-consistent approach to comparing the expectations of consumers and professionals involves estimating the New-Keynesian Phillips curve to determine which group's expectations enhance its accuracy. The Phillips curve represents inflation equations in new neoclassical synthesis models. It links inflation to expected inflation, lagged inflation, and the output gap (or another measure of economic slack). The baseline version of the model assumes heterogeneous, rational economic agents. Nonetheless, more empirically consistent versions allow for different specifications of expectations (forward- or backward-looking) and heterogenous economic agents. The heterogeneity in expectations representation can indicate whether one group of economic agents (as presented by Coibi- on and Gorodnichenko (2015; 2018)) or a subgroup with specific features (as presented by Binder (2015)) augments the Phillips curve specification.

Methodology

The empirical section consists of two parts. In the first part, we use different entropy measures to assess the common information carried by the expectations of different agents. In the second part, we compare the properties of their inflation expectations using DTW. We briefly introduce basic concepts and notions from the information theory used in the first step and DTW. In the next step, we present the study sample in detail.

Mutual information, conditional mutual information, and the global correlation coefficient

To analyse the connection between variables, we use entropy-based measures: mutual information, conditional mutual information, and the global correlation coefficient. Let us consider two random variables, X and Y, each described by its probability distributions (P_x and P_y, respectively). The entropy measures the expected uncertainty in X. We can also say that $H(X)$ is approximately equal to how much information we learn on average from one instance of random variable X (see Eq. 3).

$$H(X)--=\sum\nolimits_{x_i\in X}P_x(X=x_i)\log\left(P_x(X=x_i)\right). \tag{3}$$

Joint entropy measures the uncertainty when jointly considering two random variables, following Eq. 4.

$$H(X,Y)=-H(X,Y)=-\sum_{x_i\in X} \tag{4}$$

Mutual information (Eq. 5) measures the information about one random variable contained in another random variable. It can also be interpreted as the reduction in uncertainty of a random variable if another variable is known. Importantly, it captures the overall dependence, both linear and nonlinear, between X and Y.

$$I(X,Y)=H(X)+H(Y)-H(X,Y). \tag{5}$$

Mutual information is always positive $I(X;Y)\geq 0$ and equals 0 only if X and Y are independent. To normalise mutual information to take values from 0 to 1 (and be an alternative measure to the linear correlation coefficient), it can be transformed into the global correlation coefficient λ (as proposed in (Dionisio, Menezes, and Mendes 2004):

$$\lambda(X,Y)=\sqrt{1-\exp\left(-2I(X,Y)\right)}. \tag{6}$$

Conditional entropy quantifies the amount of information required to describe a random variable X given knowledge of a random variable Y, and is defined as follows:

$$H(X \mid Y) = H\left(X,Y\right) - H\left(Y\right). \tag{7}$$

For a clear view of entropy measures and the relationship between them, see Figure 1. Assume that X represents consumer expectations and Y represents professional expectation. Then, $H(X \mid Y)$ describes the remaining uncertainty about X given Y, i.e., what new information about X remains after knowing the professionals' expectations.

Conditional mutual information, proposed by Dobrushin (1963) and Wyner (1978), quantifies the average mutual information between random variables X and Y given knowledge of a third variable, Z. Conditioning on a third random variable may either increase or decrease the mutual information. For random variables X and Y, Z is defined according to Eq. 8

$$I\left(X,Y|Z\right) = H\left(X,Z\right) + H\left(Y,Z\right) - H\left(Z\right) - H\left(X,Y,Z\right). \tag{8}$$

If Y only reveals information about X that Z already reveals, it holds $I(X,Y \mid Z) = 0$. If X and Y are independent but $Z = X + Y$, then $I(X,Y \mid Z) = 1$. That means that Y only reveals useful information about X after observing Z. The relationships among the three variables are presented in Figure 2. Equation 8 can be rewritten to show its relationship to mutual information as:

$$I(X,Y \mid Z) = I\left(X,Y,Z\right) - I\left(X,Z\right). \tag{9}$$

Assume again that X represents consumer expectations and Y represents professional expectations, while Z is inflation two months ago, that is, it was known and published at the time of surveying expectations. $I(X,Y \mid Z)$ is the common part of the information carried by the expectations of professionals and consumers but not the part that consumers have in common with inflation.

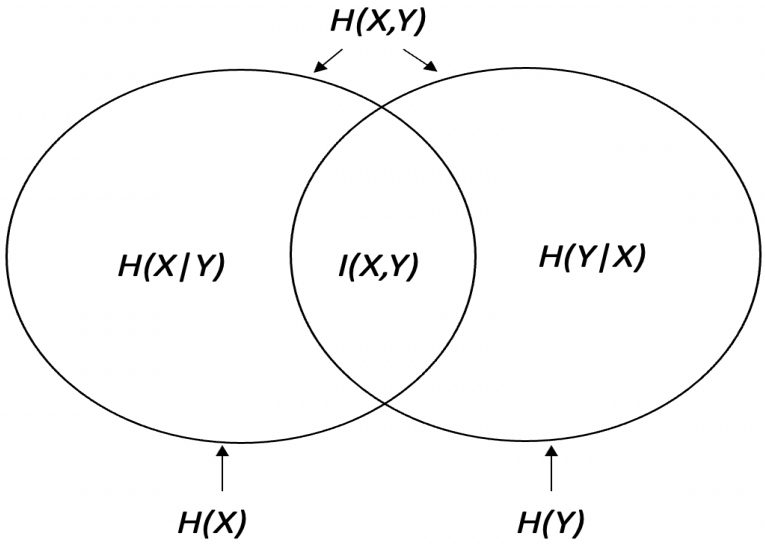

Figure 1. Visualisation of mutual information and entropy relationships

Source: own elaboration.

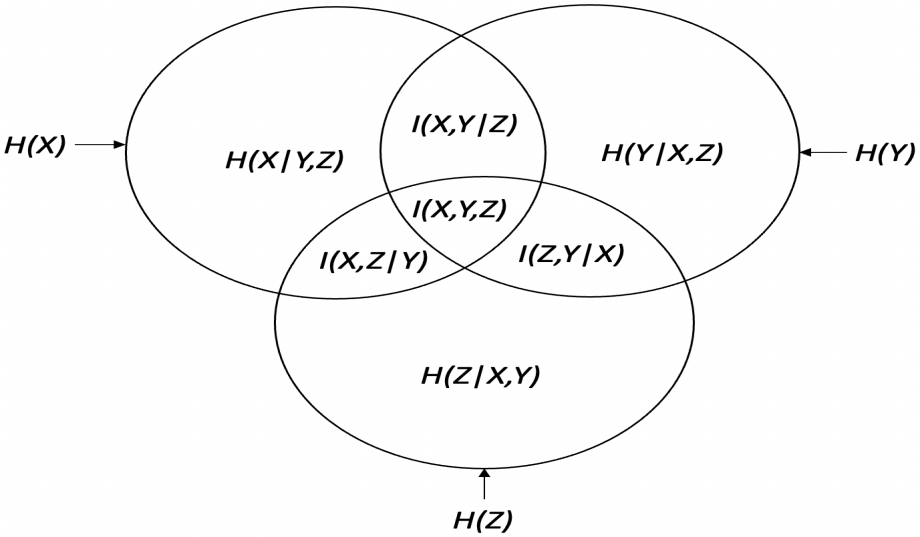

Figure 2. Visualisation of conditional mutual information and multivariate entropy relationships

Source: own elaboration.

Dynamic time warping

DTW is an algorithm for measuring the similarity/distance between two temporal sequences, which may vary in time or speed. Let us assume that we have two time series: a test, or query, $X=(x_1,...,x_N)$, and a reference $Y=(y_1,...,y_M)$. f is a non-negative, local dissimilarity function defined between any pair of elements x_n and y_m with the shortcut $d(n,m)=f(x_n,y_m)\geq 0$. In the first step, the accumulated distance (cost) matrix is calculated. Matrix D satisfies the following identities:

- $D(n,1)=\sum_{k=1}^{n} d(x_k, y_1)$, for $n \in [1:N]$,
- $D(1,m)=\sum_{k=1}^{m} d(x_1, y_k)$, for $m \in [1:M]$,
- $D(n,m)=min\{D(n-1,m-1), D(n-1,m), D(n,m-1)\}+d(n,m)$,

for $1<n\leq N$ and $1<m\leq M$.

The optimal path $p^*=(p_1,...,p_L)$ is computed in the reverse order of the indices, starting with $p_L=(N,M)$. Suppose that $p_l=(n,m)$ has been computed. If $(n,m)=(1,1)$ then $l=1$, and we are finished. Otherwise,

$$p_{l-1} := \begin{cases} (1,m-1), & \text{if } n=1 \\ (n-1,1), & \text{if } m=1 \\ argmin\{D(n-1,m-1), D(n-1,m), & \\ D(n,m-1)\}, & \text{otherwise,} \end{cases}$$

where we take the lexicographically smallest pair in case "argmin" is not unique. At the core of the technique lies the warping curve $\phi(k), k=1,\ldots,T$:

$$\phi(k)=(\phi_x(k),\phi_y(k)) \tag{10}$$

with $\phi_x(k)\in 1,...,N$ and $\phi_y(k)\in 1,...,M$, with assumptions $\phi_x(k+1)\geq\phi_x(k)$ and $\phi_y(k+1)\geq\phi_y(k)$.

The warping functions $\phi_x(x)$ and $\phi(y)$ remap the time indices of X and Y, respectively.

$$DTW=\sum_{k=1}^{T} d(\phi(k)). \tag{11}$$

To normalise DTW, we use Equation (12):

$$d_\phi(X,Y)=\sum_{k=1}^{T}\frac{d(\phi_x(k),\phi_y(k))m_\phi(k)}{M_\phi}, \tag{12}$$

where $m_\phi(k)$ is a per-step weighting coefficient and M_ϕ is the corresponding normalisation constant The idea underlying DTW is to find the optimal alignment that minimises the distance between two time series, as presented in Figure 3, according to Equation (13).

$$D(X,Y)=min_\phi d_\phi(X,Y). \tag{13}$$

In other words, one selects the deformation of the time axes of X and Y that brings the two time series as close as possible to each other. To make this alignment meaningful for a particular use, a global constraint, or window, explicitly forbids warping curves from entering some region of the (i, j) plane.

$$\left|\phi_x(k) - \phi_y(k)\right| \leq T_0, \tag{14}$$

where the warping curve $\phi(k), k = 1,\ldots,T$ and T_0 is the maximum allowable absolute time deviation between two matched elements. Windows for forward and backward-lookingness were first presented by Rutkowska and Szyszko (2022). Forward refers to the upper triangular part of the distance matrix, while backward refers to the lower part, as shown in Figure In our study, DTW inference is performed in the following steps:

1. Calculate DTW distance with forward-looking windows.
2. Calculate DTW distance with backward-looking windows.
3. Compare distances – the lower the distance, the stronger the properties.

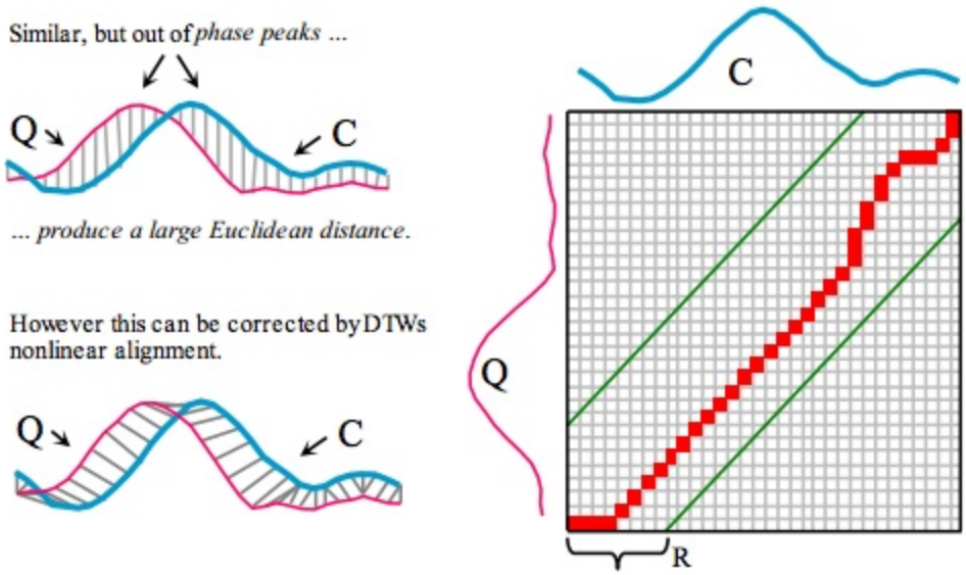

Figure 3. The idea of time-series alignment in the DTW algorithm

Source: Rakthanmanon et al. 2012.

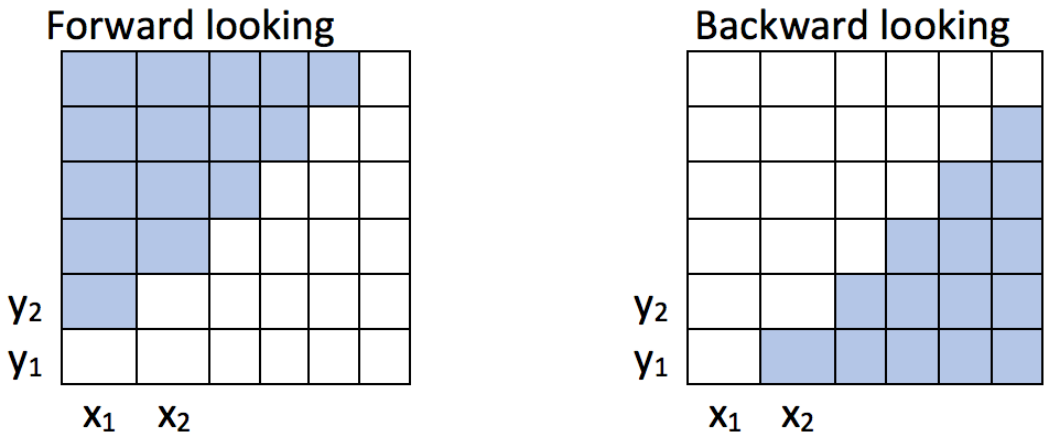

Figure 4. Backward- and forward-looking windows

Source: Rutkowska and Szyszko 2022.

Data and study steps

The sample covers 12 small open economies classified as European and implementing IT: Albania, Czechia, Hungary, Kazakhstan, Norway, Poland, Romania, Russia, Serbia, Sweden, Turkey, and the UK. We selected these countries because they run independent monetary policies under similar IT frameworks, which clearly demonstrates the need to focus monetary policy on the expectations of private agents. Despite the common IT frameworks, the sample is diverse in terms of economic development, which enables the recognition of the dependencies and co-movements of expectations among the different economies. The coverage of this study constitutes a novelty because most previous studies are about world-leading economies. The sample is suitable for testing a new method, and the study provides new insights into the economies covered. The research period varies according to the year each country adopted IT, as presented in Table 1.

Table 1. Research sample

Country	No. of observations	First observation
Albania	138	Jan. 2008
Czechia	222	Jan. 2001
Hungary	199	Dec. 2002
Kazakhstan	46	Sep. 2015
Norway	222	Jan. 2001
Poland	196	Mar. 2003
Romania	174	Jan. 2005
Russia	69	Oct. 2013
Serbia	90	Jan. 2009

Country	No. of observations	First observation
Sweden	222	Jan. 2001
Turkey	162	Jan. 2006
UK	222	Jan. 2001

Source: own elaboration.

In this study, we use three main series: (i) survey-based proxies for consumer inflation expectations, (ii) Consensus Economics' Consensus Forecast data on professional expectations, and (iii) the inflation rate (standard CPI-based inflation measure published by national statistical offices).

Consumer expectations are derived from Business and Consumer Surveys for European (European Commission 2016), Union Member States and Albania (complemented by central bank's data before May 2016), Serbia, Turkey, and the UK. The surveys do not cover Kazakhstan, Norway, or Russia, so we used survey data provided by the central banks of these economies. All surveys, except for those from Russia, are qualitative. Consumers are asked about the direction and strength of the price change compared to current inflation[4]. Expectations are quantified with the probabilistic method by Carlson and Parkin (1975) adjusted for the polychotomous (five response) survey as presented by Batchelor and Orr (1988). The method and procedure are widely accepted, so a detailed description is not provided here. For the dataset provided by the Business and Consumer Surveys, we applied a subjectified version of the quantification that assumes that perceived inflation is first quantified and then used as a scaling factor to quantify expectations. We applied a 36-month moving average of past inflation as a scaling factor for inflation perceptions. This two-step procedure weakens the relationship between expectations and inflation.

Professional expectations are derived from Consensus Economics' Consensus Forecast data. As these forecasts are fixed-event forecasts, we apply a method to transform them into fixed-horizon (12-month) forecasts (as Dovern, Fritsche, and Slacalek 2012). We investigate the dependencies of 12-month forecasts of consumers and professionals because this is the only horizon available for consumers. Consensus Forecast survey participants present the inflation forecast at the end of the current and the next calendar year. We approximate fixed-horizon forecasts as a weighted average of fixed-event forecasts. $F^{e}_{y_0,m,y_1}(x)$ denotes the fixed event forecast of variable x for year y_1 formulated in month m

4 The survey question for perceived inflation is as follows: 'How do you think consumer prices have developed over the last 12 months?' The answers to choose from include the following: 'They have… risen a lot, risen moderately, risen slightly, stayed about the same, fallen, don't know'. The survey question for the expected inflation rate is as follows: 'When compared to the past 12 months, how do you expect consumer prices to develop in the next 12 months?' The answers to choose from included the following: 'They will… increase more rapidly, increase at the same rate, increase at a slower rate, stay about the same, fall, don't know'.

of the previous year, $y_0 = y_1 - 1$. Let $F^h_{y_0,m,12}(x)$ be the fixed horizon, twelve-month-ahead forecast made at the same time. The fixed horizon forecast for the next twelve months is approximated as an average of the forecasts for the current and next calendar year weighted by their share in the forecasting horizon (Dovern, Fritsche, and Slacalek 2012):

$$F^h_{y_0,m,12}(x) = \frac{12-m+1}{12} \cdot F^e_{y_0,m,y_0}(x) + \frac{m-1}{12} \cdot F^e_{y_0,m,y_1}(x). \quad (15)$$

Results

Common information in expectations and past inflation

Mutual information analysis addresses the common information embedded within the expectations of both economic agents and past inflation. Conditional mutual information provides an overview of the alignment within a conditional context, specifically when past inflation is excluded as coordinating information. Table 2 presents the normalized mutual information between professional and consumer expectations, as well as the normalized mutual information between expectations of both groups and lagged inflation.

Romania exhibits the highest mutual information for professionals and consumers' inflation expectations, while the UK and Czechia show the lowest values. In the context of expectations, the economic interpretation of the common information suggests that professional and consumer expectations contain the same information or are aligned, as represented by the normalised mutual information coefficient (for example, approximately 76% for Poland).

This measure shows how much the expectations of one type of economic agent tell us about those of another. However, mutual information does not allow us to conclude about causality. Thus, the results can only be interpreted in terms of alignment. Mutual information is also referred to in terms of reducing the uncertainty of a random variable if another is known. In this case, it is more intuitive to refer to the reduction in consumer expectation uncertainty due to knowledge of professional expectations. This approach aligns with Carroll's epidemiological theory of expectations. However, the measure applied need not be applied only in one direction.

The strongest alignment of expectations between professionals and consumers occurs in our sample of countries with disturbed disinflation processes. This suggests that, under such circumstances, past inflation is a major factor that affects expectations for both groups of economic agents. The central banks of Czechia and the UK, for which

the time series behave the most independently, conduct forward-looking (inflation forecast-based) monetary policies. They were successful at keeping inflation at the targeted level during the period studied.

Table 2 also presents common information between expectations and inflation for both professionals and consumers. It contributes to the debate about the backward-lookingness of expectations, as it presents the common information in the expectations series and realised inflation (again lagged by two months). The case of Czechia and the UK, the two economies with the lowest mutual expectation information, is worth noting. In the UK, professionals exhibit low common information with past inflation, while that of consumers is high. Conversely, the opposite is true for Czechia. Our findings for most other sample countries except Norway mirror those of Czechia – lower mutual information between consumer expectations and past inflation than for professionals and inflation. The results of past studies suggest that consumers are more backward-looking than professionals, and they rely more on past inflation when formulating their expectations. Thus, we might expect greater alignment of expectations with past inflation for consumers, which is not true for this sample. However, this result does not necessarily mean that consumers are more forward-looking. It could mean that households ignore economic information when forming their expectations or are driven by their inflation perceptions, which normally differ substantially from actual inflation, as is well documented in the economic literature.

Table 2. Normalised mutual (I) information between professionals, consumers, and past and current inflation

Country	Professionals vs consumers	Professionals vs inflation (lag2)	Consumers vs inflation (lag2)
Albania	0.6994	0.7714	0.6636
Czechia	0.5279	0.7947	0.4418
Hungary	0.8423	0.9013	0.8058
Kazakhstan	0.6069	0.9184	0.6069
Norway	0.6729	0.6890	0.9331
Poland	0.7598	0.8911	0.7149
Romania	0.8701	0.8947	0.8178
Russia	0.5206	0.6779	0.5448
Serbia	0.8298	0.7456	0.6411
Sweden	0.6392	0.7283	0.6474
Turkey	0.7041	0.7527	0.6519
UK	0.4977	0.4976	0.7645

Source: own calculations.

Table 3. Mutual information (I) between professionals and consumers conditioned by two-month lagged inflation

Country	I (professionals, consumers)	I (professionals, consumers) conditioned inflation (lag2))
Albania	0.3358	0.3443
Czechia	0.1634	0.3100
Hungary	0.6180	0.2480
Kazakhstan	0.2297	0.0402
Norway	0.3015	0.1311
Poland	0.4305	0.2643
Romania	0.7075	0.2697
Russia	0.1580	0.1530
Serbia	0.5834	0.5199
Sweden	0.2626	0.3055
Turkey	0.3424	0.2881
UK	0.1423	0.3290

Source: own calculations.

The conditional mutual information analysis presented in Table 3 sheds light on the information content of expectations among different groups of economic agents.

First, the mutual information between the three time series – the expectations of both groups of economic agents and inflation – varies from 14% for the UK to 71% for Romania. It reveals the cross-country differences between the alignment of expectations and inflation.

Second, conditional mutual information is analysed. It represents the common information incorporated into the expectations of consumers and professionals, assuming that the information incorporated in past inflation is excluded (i.e., it is not a factor that coordinates the time series). The conditional mutual information coefficient represents the common information about inflation drivers based on other information. This coefficient reflects a more specific alignment of expectations, conditional on excluding one variable. In our sample, this alignment varies from 4% in Kazakhstan to 52% in Serbia. When the content of information incorporated into past inflation is excluded, the alignment between series is, on average, lower. This means that an important portion of the common information is about past inflation.

Third, comparing mutual information and conditional mutual information reveals that, for all cases, mutual information is greater than conditional mutual information. This suggests that the common information shared between professional and consumer expectations is based on the information content of past inflation. As both groups

of economic agents are partially backward-looking, the results confirm the importance of past inflation in shaping expectations.

Fourth, comparing mutual information among professionals, consumers, and past inflation and conditional mutual information (excluding information incorporated into past inflation) reveals two distinct cases:

1. In Hungary, Kazakhstan, Norway, Poland, Romania, Russia, Serbia and Turkey, is when common information for three variables is greater than conditional common information. This situation is standard: knowing past inflation reduces the uncertainty of inflation expectations and strengthens the alignment between series.
2. In Albania, Czechia, Sweden and the UK, conditional mutual information outperforms mutual information, meaning that knowing past inflation does not reduce uncertainty; the information content in expectations differs from past inflation.

The forward- and backward-lookingness of expectations

We used a DTW algorithm to approximate the degree of forward- and backward-lookingness of expectations. Note that the notions of FL and BL replicate the theoretical approach as described in Section 2; nonetheless, they do not bear the same meaning. The important difference is that we do not compare expectations with past or future inflation for a fixed horizon. Table 4 presents results for professionals, while those for consumers are shown in Table 5.

Table 4. Professional inflation expectations, forward- and backward-lookingness

Country	$Forward_{dist}$	$Backward_{dist}$	$Backward_{dist} - forward_{dist}$
Albania	0.1466	0.2128	0.0662
Czechia	0.2258	0.3057	0.0799
Hungary	0.2766	0.4032	0.1267
Kazakhstan	0.2785	0.8283	0.5497
Norway	0.1079	0.2897	0.1818
Poland	0.1621	0.3095	0.1474
Romania	0.3694	0.5096	0.1403
Russia	0.5287	0.7002	0.1715
Serbia	0.5475	0.4945	–0.0529
Sweden	0.1315	0.1267	–0.0049
Turkey	0.3372	0.5045	0.1674
UK	0.1893	0.2942	0.1049

Source: own calculations.

Table 5. Consumer inflation expectation properties

Country	$Forward_{dist}$	$Backward_{dist}$	$Backward_{dist} - forward_{dist}$
Albania	0.0499	0.3302	0.2803
Czechia	0.2354	0.5318	0.2964
Hungary	0.4674	0.3466	–0.1208
Kazakhstan	0.8799	1.1500	0.2701
Norway	0.1906	0.1244	–0.0662
Poland	0.1764	0.3578	0.1814
Romania	1.1675	0.4702	–0.6973
Russia	2.2784	2.5133	0.2349
Serbia	0.7550	0.4661	–0.2888
Sweden	0.1984	0.3714	0.1730
Turkey	1.6659	0.7909	–0.8750
UK	0.2110	0.2067	–0.0042

Source: own calculations.

Comparing $Forward_{dist}$ and $Backward_{dist}$ is the first step in presenting the results. When the forward-looking distance is lower than the backward-looking distance, we consider expectations to be based more on the future evolution of inflation (compared to rational expectations). Professional expectations (see Table 4) are more forward-looking for almost all countries except Serbia and Sweden. In Kazakhstan, the distance between professionals' expectations and future inflation and expectations and past inflation is the greatest, which suggests the most forward-looking expectations in the sample.

When consumers are considered (see Table 5), in six out of the twelve economies (Albania, Czechia, Kazakhstan, Poland, Russia, Sweden), consumers are more forward-looking than backward-looking. However, the distance between expectations and past inflation is lower in Hungary, Norway, Romania, Serbia, Turkey and the UK. Note that in the case of Norway and the UK, the difference between FL and BL distances is negligible, making these cases inconclusive.

When comparing the FL or BL distances reported for professionals and consumers, both distances are higher for consumers. This means that they exhibit a lower ability to recognise past or future economic situations. Consumer expectations in Turkey, Russia and Kazakhstan are much further from actual inflation than in other countries. In these economies, the disinflation process was interrupted. Russia and Kazakhstan are also the most recent adopters of IT (see Table 1). Moreover, these

economies are characterized by a relatively weak institutional environment where political factors have a strong influence on the economy. The formation of inflation expectations in such an environment is disrupted.

Alignment of expectations among professionals and consumers

Finally, this section presents the DTW-based result that reports co-movements of expectations between the two groups of economic agents. Table 6 shows the dependencies, which we understand as follows:

Consumer (professional) expectations follow professional (consumer) expectations if the distance between consumer (professional) expectations and future (forward) professional (consumer) forecasts is lower than between consumer (professional) expectations and past (lagged) professional (consumer) expectations.

In most cases, professional expectations preceded those of consumers. The situation when professional expectations precede those of consumers could be considered a standard: more educated economic agents – professionals – present their forecasts and discuss them in media. It is more likely that households use professional forecasts as drivers of their forecasts than vice versa. This is the case for most countries in our sample. In Romania and Turkey, the difference between the "consumers follow professionals" and "professionals follow consumers" cases is the most visible.

In Albania, Czechia, and Sweden, consumers do not follow professionals when following is represented by the shortest distance between professional and consumer expectations considered at different lags. The situation in Poland and the UK is inconclusive, as the difference between distances is negligible.

The most significant distances occur in Russia, regardless of which time series is considered first. This coincides with one of the lowest mutual information values for this economy between time series. However, in most cases, mutual information does not translate into lower distances between time series.

Table 6. Professional vs. consumer distances according to DTW

Country	$Forward_{dist}$	$Backward_{dist}$	$Backward_{dist} - forward_{dist}$
Albania	0.4091	0.1971	–0.2120
Czechia	0.5711	0.2467	–0.3243
Hungary	0.3128	0.5901	0.2773
Kazakhstan	0.5532	0.9844	0.4313
Norway	0.0817	0.2122	0.1304
Poland	0.2152	0.3053	0.0900

Country	$Forward_{dist}$	$Backward_{dist}$	$Backward_{dist}$ – $forward_{dist}$
Romania	0.2545	1.3904	1.1359
Russia	2.2324	2.5541	0.3217
Serbia	0.3552	0.5806	0.2254
Sweden	0.3351	0.2332	–0.1019
Turkey	0.3865	1.3225	0.9360
UK	0.3813	0.4346	0.0532

Note: $Forward_{dist}$ (first column) presents the distance between consumer expectations and (forward) professional expectations. $Backward_{dist}$ (second column) presents the distance between consumer expectations and (lagged) professional expectations. A smaller forward distance means that consumers follow professionals – a positive value in the third column.
Source: own calculations.

Conclusion

This paper presented an empirical study employing a novel combination of mutual information measures and the DTW algorithm, thanks to which we were able to obtain interesting conclusions. Mutual information captures all dependencies (including non-linear dependencies) and quantifies how much we can learn about one variable from knowing the values of another variable. The DTW algorithm does not require any assumption about time series, and because we do not assume a time shift between them, we redefine forward- and backward-lookingness without specifying a particular lag. However, it is difficult to draw any specific conclusions if the results of distance differences or different configurations of mutual information are small. This study's novelty also concerns the empirical results provided. The applied method allows us to investigate expectations from different perspectives than the standard method by accounting for non-linearities and non-stationarity in time series.

Our findings and responses to the research questions can be summarised as follows. The strongest alignment of expectations between professionals and consumers occurs in countries with disrupted disinflation processes over time (Romania and Turkey). Nonetheless, informational coordination between both groups of economic agents exists, ranging from 50% to almost 90% (Q1). A significant portion of the common information is about past inflation, regardless of whether professionals or consumers are studied. In all cases, mutual information is greater than conditional mutual information (Q2). Our sample is balanced considering consumers' forward- or backwards-lookingness (Q3). In six countries, the distance between expectations and future inflation is lower than between expectations and past inflation. Expectations mimic past inflation more than future inflation in four economies, while the results for two countries are

inconclusive. Professional expectations display a lower distance to future inflation in ten out of the twelve economies (Q4).

In terms of future research, a country-level examination that considers local monetary policies and economic circumstances would shed more light on the reported relationships. Given this study's focus on methodology, the results are only presented with a general commentary.

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Oczekiwania inflacyjne konsumentów i profesjonalistów – własności i wzajemne zależności

Oczekiwania inflacyjne są kluczową zmienną dla banków centralnych. Jednak empiryczne badanie ich właściwości stanowi wyzwanie. Celem tego badania jest porównanie właściwości oczekiwań konsumentów i profesjonalistów oraz ocena nastawienia na przyszłość i informacji zawartej w oczekiwaniach tych grup uczestników rynku. W badaniu zastosowano miary oparte na entropii, aby uchwycić nieliniowe zależności między zmiennymi i algorytm dynamicznej transformaty czasowej (DTW) oraz uwzględnić różne opóźnienia w relacjach. Badanie obejmuje 12 gospodarek regionu europejskiego, w których realizowana jest strategia celu inflacyjnego. Wyniki sugerują, że w większości krajów profesjonaliści bardziej wybiegają w przyszłość, a konsumenci podążają za profesjonalistami. Obie grupy podmiotów gospodarczych prezentują oczekiwania zgodne pod względem zawartości informacyjnej. Występują różnice między krajami. Wyniki badań potwierdzają, że komunikacja i inne działania banków centralnych, nakierowane na kształtowanie oczekiwań, nawet jeśli skierowane są głównie do specjalistów, nie pozostają bez znaczenia dla konsumentów. Wartość dodana badania wynika z zastosowania alternatywnej metody oceny oczekiwań, pozwalającej na uniknięcie wad metod standardowych oraz na wyciągnięcie szerszych wniosków na temat zależności.

Słowa kluczowe: oczekiwania inflacyjne, wzajemna informacja, algorytm DTW