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Tale about Inflation Tails[*]

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Abstract

We study probabilities of extreme inflation events in the United States and the euro area. Using a state-space model that incorporates information from a large set of professional forecasters, we generate the term structure of inflation forecasts as well as probabilities of future inflation for any range of inflation outcomes in closed form at any horizon. Since the onset of the COVID-19 pandemic, inflation expectations increased materially amid heightened uncertainty about future inflation. Likelihood of significant departures of inflation targets in the longer term reached about 15 percent in the middle of 2022, increasing from near zero levels in 2020. Such an increase in the right tail of the probability distribution over future inflation outcomes drives an increase in inflation expectations and inflation risk premiums. Several popular external uncertainty measures are associated with variation in tail probabilities.

JEL Classification: G12, G13, G14
Keywords: Inflation forecasts, inflation state-space model, probability of rare inflation events, inflation anchoring

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1 Introduction

In 2022, consumer price inflation in the United States and the euro area reached the highest levels seen in decades, driven in large part by COVID-19-induced supply chain imbalances and geopolitical developments. Central banks responded by raising their policy rates and communicating their strong commitment to bring inflation back to their respective inflation objectives. In particular, the European Central Bank (ECB) stated in its February 2, 2023 Monetary Policy Statement (European Central Bank, 2023): "*The Governing Council will stay the course in raising interest rates significantly at a steady pace and in keeping them at levels that are sufficiently restrictive to ensure a timely return of inflation to its 2% medium-term target.*" Also, the Federal Reserve Board Chair, Jerome Powell, stated in the Federal Reserve's testimony before the Committee on Banking, Housing, and Urban Affairs at the U.S. Senate (Powell, 2023): *"Although inflation has been moderating in recent months, the process of getting inflation back down to 2 percent has a long way to go and is likely to be bumpy. As I mentioned, the latest economic data have come in stronger than expected, which suggests that the ultimate level of interest rates is likely to be higher than previously anticipated."*

Given the importance of a timely return to central banks' inflation targets, gauging and analyzing developments in inflation expectations is a major focus of macroeconomics and monetary policy literature. One of the tools that central bankers around the world use to measure inflation expectations is so-called inflation compensation, or the difference between the nominal and inflation-adjusted (real) rates of comparable maturities. Inflation compensation measures how much compensation investors in nominal bonds require over holding inflation-adjusted debt, such as Treasury Inflation-Protected Securities (TIPS). For studies related to the U.S., see, for example, Gürkaynak, Sack, and Wright (2007), Gürkaynak, Sack, and Wright (2010), Christensen, Lopez, and Rudebusch (2010), Grishchenko and Huang (2013), D'Amico, Kim, and Wei (2018), and Chang (2019), to name just a few. For studies in the U.K., Japan, and the euro area, see, for example, Barr and Campbell (1997), Evans (1998), and Kita and Tortorice (2018). However, market-based inflation compensation measures are affected by inflation risk premiums — compensation for risk required by the market participants in the nominal bond market since the real value of nominal bonds declines with increasing inflation — that are time varying and can be large and, therefore, can distort inflation expectations readings based solely on inflation compensation (See, for example, Campbell and Viceira, 2001; Buraschi and Jiltsov, 2005; Ang, Bekaert, and Wei, 2008; Hördahl and Tristani, 2010; Ajello, Benzoni, and Chyruk, 2020; Chernov and Mueller, 2012; Haubrich, Pennacchi, and Ritchken, 2012;

Abrahams, Adrian, Crump, and Moench, 2013; Grishchenko and Huang, 2013; Fleckenstein, Longstaff, and Lustig, 2013; Crump, Eusepi, and Moench, 2016; D'Amico, Kim, and Wei, 2018; Breach, D'Amico, and Orphanides, 2020).

This paper provides inflation expectations readings based on the wide set of inflation forecasts contained in surveys of professional forecasters. Surveys have been documented to be successful in forecasting inflation relative to various time-series models (for example, Ang, Bekaert, and Wei, 2007; Aruoba, 2020). The advantage of using surveys of professional forecasters is that, unlike market-based readings of inflation expectations, they are free from inflation risk premiums. Using surveys, we achieve a dual goal. First, we provide a term structure of inflation expectations. Second, we compute inflation risk premiums, by comparing market-based inflation compensation rates (either TIPS- or inflation swap-based) and model-implied inflation expectations of comparable maturities.

We build our framework on the state-space model of Grishchenko, Mouabbi, and Renne (2019, GMR). This model presents a sophisticated way to jointly aggregate survey-based inflation expectations and survey-based distributions over future inflation outcomes available in the U.S. and the euro-area surveys of professional forecasters. The model produces the term structures of inflation expectations (inflation expectations curve) in respective economic areas. The model also uses the second moments of survey-based distributions of future inflation rates and aggregates them into the term structures of inflation uncertainty (inflation uncertainty curve) in respective economic areas.[1] In addition, the model extracts signals about inflation forecasts from several surveys in two economic areas (the U.S. and the euro area). In addition to modeling inflation forecasts at different horizons, importantly, we attempt to answer questions related to the balance of risks surrounding inflation expectations. We achieve it in three ways. First, we provide a measure of uncertainty about future inflation because the GMR model allows the volatility of inflation to vary over time.[2] We estimate the stochastic volatility of inflation using the second moments of the probability distributions about future inflation available in several surveys of professional forecasters.

Second, we compute the GMR anchoring measure of inflation expectations — the probability of

[1]The fact that the inflation state-space model matches second-order moments presents an important distinction between our approach and the one developed by Aruoba (2020). The latter study also uses a statistical model to aggregate various surveys to produce a term structure of inflation expectations. However, Aruoba (2020)'s approach implicitly assumes that inflation uncertainty is constant over time. In addition, Aruoba (2020) focuses on inflation forecasts in the U.S. only, while we focus on modeling inflation expectations and uncertainty curves jointly for the U.S. and euro area.

[2]Engle (1982) was the first who emphasized time-varying inflation uncertainty in the context of an econometric model by specifying a new class of stochastic processes — autoregressive conditional heteroscedastic (ARCH) processes. Zarnowitz and Lambros (1987) emphasized time-varying inflation uncertainty in the context of the second moment of survey-based inflation distributions; the concept that we use in our model to proxy for inflation uncertainty.

future inflation being in a certain range around the central banking target. There are several proposed measures of anchoring, or stability of inflation expectations, such as a response of market-based inflation compensation measures or interest rates to incoming macroeconomic news (Gürkaynak, Levin, Marder, and Swanson, 2007; Mishkin, 2007; Beechey, Johannsen, and Levin, 2011; De Pooter, Robitaille, Walker, and Zdinak, 2014; Speck, 2016), a response of (changes in) long-term inflation expectations to (changes in) short-term ones (Buono and Formai, 2016; Gerlach, Moessner, and Rosenblatt, 2017), the precision around estimates of the level of inflation (Mehrotra and Yetman, 2014), the volatility of shocks to trend inflation (Mertens, 2016), and the closeness of average beliefs to the central bank's inflation target (Kumar, Afrouzi, Coibion, and Gorodnichenko, 2015; Łyziak and Paloviita, 2016). The difference between these measures and the GMR anchoring measure is that most of them are mainly related to the stability of the conditional mean of inflation and do not capture the conditional variance of inflation that can be relatively high even though the conditional mean is close to the target.[3]

Third, we compute probabilities of future inflation being higher than a certain threshold (tail probabilities) in closed form. We can accomplish this because the GMR model is highly tractable — it offers closed-form solutions for first and second conditional moments of future inflation rates at *any horizon* — due to the fact that the factors in our econometric model, including those driving inflation uncertainty, follow so-called affine processes.[4]

An additional advantage of our model is that it uses survey inflation forecasts rather than market quotes. Kitsul and Wright (2013) and Hilscher, Raviv, and Reis (2022) use inflation options to extract information about probabilities of extreme inflation events. However, recently, trading in the market for inflation options has been very low, if not virtually nonexistent, meaning that it is not clear whether market participants could actually trade at the provided quotes, or whether those quotes represent the views of market participants. Instead, we use a model that relies on the most up-to-date surveys that provide distributions over future inflation outcomes and thus reflect information about extreme inflation outcomes.

Our findings are as follows. First, our model implies that both short- and long-term inflation expectations increased dramatically after the onset of the COVID-19 pandemic but moderated somewhat at

[3]Consider, for instance, a situation where a macroeconomic surprise results in a substantial increase in the long-term conditional variance but has no effect on the conditional mean. That is, suppose we face equal increases in both downside and upside risks. In this situation, while long-term inflation expectations remain stable, the probability of having very high or very low future inflation rates increases substantially, which is at odds with the concept of anchoring.

[4]The affine property of our factors implies that the model can be easily cast in state-space form and subsequently estimated using Kalman filtering techniques. In particular, these techniques handle missing observations, which is particularly useful in our case, because various surveys are released at different points in time.

the end of our sample, in late 2022 and beginning of 2023. Nevertheless, short-term expectations remain notably higher than longer-term inflation expectations, both in the U.S. and the euro area. Second, our model implies that uncertainty about future inflation, as measured by the second moment of the fitted survey probability distribution over future inflation outcomes, increased significantly in 2021-2022 but has declined since then. We find that inflation uncertainty is currently around the levels last seen just before the Global Financial Crisis (GFC). Third, the probability of U.S. five-year average inflation exceeding 3 percent increased substantially and the probability of U.S. five-year average inflation falling below 1 percent declined substantially. Namely, our model implies that the probability of higher-than-3-percent average inflation over the next five years was around 25 percentage points in January 2023, compared with ten percentage points in early 2020. Likewise, higher-than-3-percent probability of euro-area inflation in the next five years reached about 12 percentage points in late 2022 compared with only 4 percentage points in the wake of the COVID crisis. Last, inflation risk premiums increased in 2021 but declined since then. Inflation risk premiums for longer-horizons became positive in 2022, which is notable because estimates for inflation risk premiums usually hover around zero levels (see, for example, Grishchenko and Huang, 2013, and references above). We have also explored relationship between model-implied inflation tail probabilities and popular external uncertainty measures, such as macroeconomic, real economic, and financial uncertainty measures developed in Jurado, Ludvigson, and Ng (2015), economic policy uncertainty measures developed in Baker, Bloom, and Davis (2016), and a geopolitical risk measure developed in Caldara and Iacoviello (2022). In general, we found that variation in inflation tail probabilities in both economic areas appears to be associated with variation in these uncertainty measures, depending on tail probabilities and considered horizon.

The rest of the paper is organized as follows. Section 2 describes the surveys of professional forecasters we use to aggregate inflation forecasts of future inflation at different horizons and estimate inflation expectations and inflation uncertainty curves for the U.S. and the euro area. Section 3 describes the inflation state-space model and the surveys' fit to the model. Section 4 describes our empirical results and Section 5 concludes.

2 Data

Section 2.1 and 2.2 briefly discuss available data in the U.S. and euro-area surveys, respectively. Our data is since the onset of the euro area in January 1999 until February 2023, with different surveys available in different frequencies and publishing forecasts for different horizons.

2.1 Surveys of inflation forecasts in the United States

Surveys in the US used in our study include the following four surveys. Panel A of Table 1 summarizes the surveys of professional forecasters in the United States.

The Survey of Professional Forecasters (US SPF) published by the Federal Reserve Bank of Philadelphia is conducted quarterly and provides forecasts on a wide range of macroeconomic and financial variables since 1968:Q4.[5] For the purpose of this study, we use several inflation forecasts from the US-SPF.

First, we use density forecasts — available in the form of histograms — for the price change in the GDP price deflator (survey variable PRPGDP) for the current and the following calendar year.[6] The density functions are available on an individual forecaster basis and we aggregate this information by using the average forecast density functions. The US-SPF defines a price change as the annual-average over annual-average percent change in the level of the GDP price index that is available quarterly. Note that forecast density functions are the *fixed event* forecasts (they target the current and the next calendar years), therefore, the forecast horizon changes with the survey's timing. Our sample for the density functions is from 1999:Q1 to 2022:Q4.[7]

Second, we use the US SPF five-year average headline CPI inflation consensus forecasts (survey variable: CPI5YR) in order to identify longer-horizon inflation forecasts. This projection is defined as the annual average inflation rate over the next five years. The "next five years" includes the year in which the survey is conducted and the following four years. Our sample for this variable spans from 2005:Q3 (its starting point in the US-SPF) to 2022:Q4.

The Blue Chip surveys — The Blue Chip Financial Forecasts (BCFF) and Blue Chip Economic Indicators (BCEI) surveys — are published monthly. Both Blue Chip surveys provide individual point estimates of inflation forecasts, from which consensus and disagreement measures can be

[5] The US SPF survey was formerly conducted by the American Statistical Association and the National Bureau of Economic Research and was taken over by the Philadelphia Fed in 1990:Q2.

[6] US-SPF started providing density projections of the core Consumer Price Index (survey variable PRCCPI) and of the core Personal Consumer Expenditures Index (survey variable: PRCPCE) only in 2007:Q1. Therefore we concentrate on the density projections of the GDP price deflator (despite small level differences with the headline CPI index) in order to have information about the second moments of the future U.S. inflation rates starting from the beginning of our sample, 1999:Q1. The US-SPF does not provide any density projections about headline CPI inflation.

[7] The beginning of our sample is motivated by the onset of the euro-zone and availability of the euro-area surveys.

obtained. Monthly surveys provide inflation forecasts up to six quarters out. In addition to those, BCFF and BCEI surveys publish long-range forecasts twice a year.[8] These long-range forecasts contain average annual forecasts usually five years out from the survey publication year and the average five-year forecast five years ahead. We use five-year, five-years-ahead consensus inflation forecasts in our model estimation.

The Survey of Primary Dealers (US SPD) is published by the Federal Reserve Bank of New York since 2004. In advance of each Federal Open Market Committee (FOMC) meeting, the survey provides primary dealers' macroeconomic forecasts including inflation forecasts.[9] Relative to inflation forecasts available in the US SPF, the US SPD provides inflation forecasts for the longer horizons: Namely, probability distributions of the average annual five-year ahead CPI inflation and of the five-year five-years-ahead average annual CPI inflation. The survey is published at the FOMC frequency.

The Consensus Economics Survey (CES) provides consensus inflation forecasts for a range of developed countries, on a monthly basis. US average annual inflation forecasts are available for the current and the next calendar year, from which we extrapolate a fixed horizon one-year-ahead inflation forecast.

2.2 Surveys of inflation forecasts in the Euro Area

Surveys in the euro area used in our study include the following two surveys. Panel B of Table 1 summarizes the euro-area data set described below.

The European Central Bank Survey of Professional Forecasters (ECB SPF) provides various macroeconomic forecasts in the euro area including inflation forecasts since 1999, the onset of the euro area. In particular, the survey provides, as in the case of the US SPF and the US SPD, the probability distributions of inflation for the current and the next calendar year, and for a longer horizon (five-year-ahead). Inflation is defined as the change in the Harmonized Index of Consumer Prices (HICP).

[8] BCFF publish long-range forecasts in June and December, and BCEI publish them in March and October, so these forecasts are not evenly spaced out through the year.

[9] The survey questions sometimes vary depending on the economic environment. See posted questions on the website of the Federal Reserve Bank of New York: https://www.newyorkfed.org/markets/primarydealer_survey_questions.html. Nonetheless, certain questions such as the density forecasts for headline CPI inflation are routinely asked.

The CES provides long-term euro-area consensus inflation forecasts on a semi-annual basis (in April and October), in which five-year five-year-ahead inflation forecasts are available. These forecasts are available since 1999, the onset of the euro area.

3 State-Space Model of Surveys of Professional Forecasters

In this section, we briefly outline the GMR state-space model according to which we compute inflation expectation, inflation uncertainty, and probability of inflation being in a certain range in the analytical form. We estimate the model using the Kalman filter methodology — an algorithm that is usually used for estimating of state-space models. A state-space model consists of two types of equations: transition equations and measurement equations. Transition equations describe the dynamics of the latent factors, discussed below in Section 3.1. Measurement equations specify the relationship between the observed variables and the latent factors, discussed further in Section 3.2. Conditional on the model parameterization and on observed variables, the Kalman filter computes the distribution of the latent variables. Besides, a by-product of the algorithm is the likelihood function. Model parameters can therefore be estimated by numerically maximizing this function. Once this is done, the last pass of the algorithm provides estimates of the latent variables.[10] We discuss the fitting of survey data to model-implied moments of distribution in Section 3.3.

3.1 Transition equations of inflation and its driving factors

We assume that the annual inflation rate, $\pi^{(i)}_{t-12,t}$, is a linear combination of factors gathered in the $n \times 1$ vector $Y_t = (Y_{1,t}, \dots, Y_{n,t})'$. As specified below, the dynamics of Y_t is such that the marginal mean of Y_t is zero. Importantly, $Y_{j,t}$ factors, where $j \in \{1, \dots, n\}$, may be common to different economies:[11]

$$\pi^{(i)}_{t-12,t} = \pi^{(i)} + \delta^{(i)\prime} Y_t. \tag{1}$$

We assume that the distribution of Y_t is Gaussian conditionally on its past realization $\underline{Y_{t-1}} = \{Y_{t-1}, Y_{t-2}, \dots\}$ and on another $q \times 1$ exogenous vector $z_t = (z_{1,t}, \dots, z_{q,t})'$ that affects the variance of Y_t.[12] Specifically,

[10] We refer the reader to the GMR paper for more specific details on model estimation.

[11] U.S. and euro-area inflation rates are weighted averages of state-level and country-level inflation rates, respectively. Modelling such disaggregated inflation rates may help investigate questions such as the extent to which extent de-anchoring in one area relates to cross-region heterogeneity. This is however beyond the scope of this paper.

[12] Note that this does not imply that the marginal distribution of Y_t is Gaussian (as it is in GARCH models).

Y_t is given by:

$$Y_t = \Phi_Y Y_{t-1} + diag\left(\sqrt{\Gamma_{Y,0} + \Gamma'_{Y,1} z_t}\right)\varepsilon_{Y,t}, \quad \varepsilon_{Y,t} \sim \mathcal{N}(0, I), \tag{2}$$

where $\Gamma_{Y,0}$ is an $n \times 1$ vector and $\Gamma_{Y,1}$ is a $q \times n$ matrix. According to eq. (2), z_t affects the conditional variance of Y_t. Given that the vector z_t is essential for modelling the time-varying variance of inflation, we refer to it as the uncertainty vector (and to the $z_{j,t}$'s as the uncertainty factors) hereinafter.

The specification of the conditional variance in eq. (2) implies that the entries of $\Gamma_{Y,0} + \Gamma'_{Y,1} z_t$ have to be non-negative for all t. To that end, we assume that all elements of Γ_Y vectors are non-negative and that z_t follows a multivariate auto-regressive gamma process. As shown in GMR Appendix A.4, the dynamics of z_t admits the following semi-strong VAR representation:

$$z_t = \mu_z + \Phi_z z_{t-1} + diag\left(\sqrt{\Gamma_{z,0} + \Gamma'_{z,1} z_{t-1}}\right)\varepsilon_{z,t}, \tag{3}$$

where, conditional on $\underline{z_{t-1}}$, $\varepsilon_{z,t}$ has a zero mean and a unit diagonal covariance matrix, and where $\Gamma_{z,0}$ is a $q \times 1$ vector and $\Gamma_{z,1}$ is a $q \times q$ matrix.

Given the dynamics of Y_t and z_t, the semi-strong VAR form of the dynamics followed by $X_t = (Y'_t, z'_t)'$ is:

$$X_t = \begin{bmatrix} Y_t \\ z_t \end{bmatrix} = \mu_X + \Phi_X \begin{bmatrix} Y_{t-1} \\ z_{t-1} \end{bmatrix} + \Sigma_X(z_{t-1})\varepsilon_{X,t}, \tag{4}$$

where $\varepsilon_{X,t}$ is a $(n+q)$-dimensional unit-variance martingale difference sequence, $\mu_X = (\mathbf{0}_{1\times n}, \mu'_Y)'$, Φ_X is a block-diagonal matrix with Φ_Y and Φ_z on its diagonal and $\Sigma_X(z_{t-1})\Sigma_X(z_{t-1})'$ — that is, the conditional covariance matrix of X_t (given its own past) is a diagonal matrix whose diagonal entries are linear in z_{t-1}.[13]

An important property of X_t is that it is affine. This implies that, conditionally on $\underline{X_t} = \{X_t, X_{t-1}, \dots\}$, the first and second conditional moments of any linear combination of future values of X_t are affine functions of X_t. In particular, since the realized log annual growth rate of the price index $\pi^{(i)}_{t-12,t}$ is an affine transformation of X_t (eq. (1)), its first and second moments can be written as affine functions of the X_t

[13] Specifically, the first n diagonal entries are the components of $\Gamma_{Y,0} + \Gamma'_{Y,1}(\mu_z + \Phi_z z_{t-1})$ and the last q are those of $\Gamma_{z,0} + \Gamma'_{z,1} z_{t-1}$.

factors as well:

$$\mathbb{E}_t(\pi^{(i)}_{t+h-12,t+h}) = \pi^{(i)} + a^{(i)}_h + b^{(i)\prime}_h X_t \tag{5}$$

$$\mathbb{V}ar_t(\pi^{(i)}_{t+h-12,t+h}) = \alpha^{(i)}_h + \beta^{(i)\prime}_h X_t, \tag{6}$$

where $\mathbb{E}_t(\bullet)$ and $\mathbb{V}ar_t(\bullet)$, respectively, denote the expectations and variances conditional on $\underline{X_t}$. As explained in Section 2, we have to consider other measures of inflation because of the nature of the different surveys we fit.[14]

3.2 Measurement equations

The state-space model involves three types of measurement equations:

(a) The first set of equations states that, for each economic area i, a realised inflation rate is equal to a linear combination of factors Y_t, as stated by eq. (1), with area-specific loadings $\delta^{(i)}$'s, measured without an error.

(b) The second set of equations states that, up to the measurement error, survey-based expectations of future inflation rates are equal to the model-implied ones:

$$SPF_t = \boldsymbol{\pi} + \mathbf{a} + \mathbf{b}' X_t + diag(\sigma^{avg})\eta^{avg}_t, \tag{7}$$

where η^{avg}_t is a vector of *iid* Gaussian measurement errors; SPF_t gathers all survey-based inflation expectations available at date t; and the vector $\boldsymbol{\pi}$, the vector $\mathbf{a}$, and the matrix of factor loadings $\mathbf{b}$ are filled with the appropriate $\pi^{(i)}$'s and with the parameters defining the affine relationships between conditional expectations and X_t.

(c) The third set of equations states that, up to the measurement error, survey-based variances are equal to the model-implied ones, that is:

$$VSPF_t = \boldsymbol{\alpha} + \boldsymbol{\beta}' X_t + diag(\sigma^{var})\eta^{var}_t, \tag{8}$$

[14] In particular, annualized h-period ahead inflation rates $\pi^{(i)}_{t,t+h} = (12/h)\log(P^{(i)}_{t+h}/P^{(i)}_t)$ can be written as: $\pi^{(i)}_{t,t+h} = \pi^{(i)} + \frac{1}{k}\delta^{(i)\prime}(Y_{t+12} + Y_{t+24} + \cdots + Y_{t+h})$, where $h = 12 \times k$. Because $\pi^{(i)}_{t,t+h}$ is affine in Y_t (and therefore in X_t), the first and second conditional moments of $\pi^{(i)}_{t,t+h}$ can also be written as affine functions of X_t. The same applies to quarterly average definitions of inflation $\bar{\pi}^{(i)}_{t,t+h}$ that some surveys adopt (see Table 1). In the following, vectors such as $b^{(i)}_h$ and $\beta^{(i)}_h$ — and their equivalent for other definitions of inflation rates such as this one — are called factor loadings. Appendix A.3 in GMR provides recursive algorithm used to compute them.

where η_t^{var} is a vector of *iid* Gaussian measurement errors, $VSPF_t$ gathers all survey-based conditional variances of inflation forecasts available at date t, and the vector $\boldsymbol{\alpha}$ and the matrix of factor loadings $\boldsymbol{\beta}$ are filled with the parameters defining the affine relationships between conditional variances and X_t (such as eq. 6).

Let's denote S_t as the vector of observations used in the state-space model. Since the latter is based on equations of types (a), (b) and (c), we have $S_t = [\pi_t^{(1)}, \pi_t^{(2)}, SPF_t', VSPF_t']'$.[15] Using obvious notations, the measurement equations of the state-space model read:

$$S_t = A + B'X_t + diag(\sigma^S)\eta_t^S, \tag{9}$$

where $\mathbb{V}ar(\eta_t^S) = Id$. Although measurement errors associated with the different components of S_t are not correlated, the elements of S_t may co-vary through their common dependence on X_t. This will allow the model to capture the joint fluctuations of inflation forecasts associated with different horizons.

3.3 Model Fit to Surveys' Data

Figure B.1 shows the model-implied five- and five-to-ten-year inflation expectations along with consensus inflation expectations from the Blue Chip and SPF surveys. According to the panel of the figure, the five-year GMR model-implied inflation expectations (shown by the dashed red line) fit the survey forecast data relatively well, indicating the model's ability to compromise between various surveys' forecasts. In particular, an increase in model-implied five-year inflation expectations in the latter part of the sample appears to be driven largely by an increase in the U.S. SPF consensus five-year ahead inflation forecasts (shown by the purple squares). In contrast, model-implied five-to-ten-year inflation expectations are primarily driven by the US SPD inflation forecasts (shown by the black circles), according to the bottom panel of this figure. Figure B.2 shows the model-implied measure of inflation uncertainty (in dashed red line), computed as the square root of the model-implied second moment of the inflation distribution (given by eq. (8)) for five- and five-to-ten year inflation horizons, the the square root of the second moment of of the U.S. SPD-based density distribution. The model appears to fit the second moment of the density distribution relatively accurately in the sample since 2015 — when the five-year density forecast becomes

[15] Overall, there are 24 measurement equations in the model: the first two measurement equations correspond to the euro-area and the U.S. (realized) year-on-year inflation rates $\pi_{t-12,t}$, the following 12 measurement equations correspond to the conditional expectations (whose observed values are gathered in vector SPF_t) and, finally, the last 10 measurement equations correspond to the conditional variances (whose observed values are gathered in $VSPF_t$).

available — yet, the model has some difficulty fitting five-to-ten-year survey density forecasts prior to 2015.

Figure B.3 shows the fit of the ECB SPF consensus inflation forecasts to the estimated inflation expectations series in the euro area, at one- and four-to-five-year horizons.[16] According to the top panel of the figure, one-year ahead model-implied expected inflation series (shown by the dashed red line), the ECB SPF inflation for the next calendar year (shown by the blue x's), and the calendar year following the next calendar year (shown by the purple squares) track each other pretty closely, albeit the next calendar series appear to have more variation around the estimated inflation series. According to the bottom panel of the figure, four-to-five-year model-implied expected inflation appears to fit the ECB SPF five-year ahead inflation forecasts closely. Figure B.4 shows the comparison between the second moment of the euro-area inflation distribution of the ECB SPF for one- and four-to-five-year horizons and comparable model-implied second moments of the distribution.[17] The model appears having difficulty fitting the second moment of the ECB SPF for both horizons, especially in the first half of the sample.

4 Empirical Results

Section 4.1 discusses the model estimates for the inflation expectations and inflation uncertainty curves, Section 4.2 — the model estimates of the inflation anchoring measures and inflation tail probabilities, Section 4.3 — inflation risk premium estimates, and Section 4.4 — the regression results associated with variation in tail probabilities and external uncertainty measures.

4.1 Inflation Expectations and Uncertainty Curves

4.1.1 The United States

Table 2 reports summary statistics for model-implied average inflation rates over different horizons. Because of the affine properties of the GMR model, expected inflation rates are available in closed form for any horizon essentially allowing us to infer a survey-consistent term structure of inflation expectations. For the U.S., we report results for one-, five-, ten-, and five-to-ten-year horizons. For the euro area, we report results for one-, four-, five-, and four-to-five-year horizons. The reason in reporting different horizons is because the Fed targets the long-term (five-to-ten-year) horizon and the ECB targets the

[16] The reason that we plotted expected inflation at this horizon in the bottom panel of Figure B.3 is because this horizon is in range of the ECB's medium-term inflation target.

[17] The ECB SPF is the only survey for which the density forecast for the euro-area inflation is available.

medium-term (four-to-five-year) horizon.[18] We report results for 5 subperiods: for December 1998 to January 2023 (full sample period) and several subsample periods: December 1998 to December 2008 (a period that precedes the GFC), January 2009 to December 2015 (a period that encompasses the GFC and the zero-lower bound (ZLB) periods), January 2016 to February 2020 (a period that follows the ZLB period), and March 2020 to January 2023 (a period that includes the onset of the COVID-19 pandemic and the years following).[19][20] In the full sample period, U.S. inflation expectations run around 2 percent for one-, five-, and ten-year horizons. For the five-to-ten-year horizon, inflation is expected to run slightly above 2 percent (the point estimate is 2.31 percent with the standard deviation of 0.19 percent). Consistent with low inflation environment the GFC, ZLB, and post-ZLB periods (lines 3 and 4 in Panel A), the model-implied expected inflation point estimates are lower than in the other conisdered subsamples but expected inflation runs considerably higher in the COVID-19 period. In fact, one- and five-year expectations are 3.27 and 2.59 percent, respectively, and have substantial volatility in those series reflecting the volatile nature of realized inflation and surrounding uncertainty in those series. However, five-to-ten-year point estimate of expected inflation is 2.14 percent (standard deviation of 0.10 percent) — very close to the Fed's inflation target of 2 percent.

Figure 2 shows times series of expected inflation and uncertainty in the U.S.. The top panel shows that 1-year expected inflation (solid black line) peaked above 5 percent (amid materially increased economic uncertainty as shown in the bottom panel) from very suppressed levels during the COVID period, clearly reflecting recent global price pressures on near-term inflation expectations. Longer-term measures, namely, five- and ten-year average inflation expectations (red dashed and blue dotted lines) — increased considerably as well, to levels around 3.5 and 3 percent, respectively. Interestingly, five-to-year-year expected inflation (purple dash-dotted line) continues to hover just above 2 percent, likely reflecting surveys' respondents confidence in the central banks' commitment to meet in the inflation targets in the longer term.

GMR model-implied term structures of inflation expectations and inflation uncertainty shown in Figure 3 provide similar insights but in a cross-section rather than in a time series dimension. Panel A shows term structures of forward one-year expected inflation rates in January 2020, January 2021, January 2022, and January 2023. The effect of realized inflation on near-term inflation expectations is obvious.

[18] Inflation targets for these horizons serve as motivations for asking respondents about these specific horizons' forecasts in the U.S. and the euro-area surveys, respectively.

[19] World Health Organization (WHO) declared the start of the global COVID-19 pandemic on March 11, 2020. See https://www.yalemedicine.org/news/covid-timeline.

[20] We report statistics for the same five subperiods in Tables 2 through 9 when we present model-implied results.

Recall that realized inflation series of both economic areas are included in our measurement equations. Thus, realized inflation affects inflation expectations via two interconnected channels: (a) explicitly - via realized inflation measurement equations; and (b) implicitly - via higher survey inflation forecasts due to higher realized inflation. The model had forecast an almost flat term structure of expectations back in January 2020 and January 2021 when realized inflation was low (see Panel A of Figure 1). However, the model's forecast changed materially in January 2022 and January 2023: The term structure increased and became sharply downward-sloping in the near term from about 4 percent to roughly 2.3 percent in the medium term, which is around five-year horizon. The model also forecast a slightly higher level of inflation expectations in January 2023 relative to a year ago corroborating a story of lingering global price pressures. Panel B of Figure 3 shows the term structure of forward one-year inflation uncertainty rates for the same months as Panel A does.[21] The model forecasts a significant increase in uncertainty between January 2021 and January 2022 relative to earlier periods and another notable increase in uncertainty between January 2022 and January 2023, especially in the near term. In fact, the term structure of inflation uncertainty was upward-sloping in 2020 and 2021 (black solid and dashed red lines) in near to medium term — before it has leveled out in the longer term — and became hump-shaped in 2022 and 2023 (dotted blue and purple dash-dotted lines). The model predicts that uncertainty will remain high in the next few years and will be the highest about three years from now. After that, the model forecasts that uncertainty will subside.

4.1.2 The Euro Area

Turning to inflation expectations in the euro area, Panel B of Table 2 shows that inflation expectations run about 1.9 percent in the full sample, and below the 2 percent target at all horizons. Even though the one-year expected inflation has been 2.53 percent amid considerable volatility since the onset of the COVID-19 pandemic, the four-to-five-year expected inflation has remained around 1.8 percent even during the COVID-19 pandemic, as in the full sample. These estimates are broadly consistent with the ECB's declared goal of *"close but slightly below 2 percent"* and with the GMR finding that the euro-area expectations have been somewhat better anchored than the U.S. expectations.[22] Figure 4 shows a time series of expected inflation uncertainty for the same horizons as reported in Panel B of Table 2. The top panel shows that one-year expected inflation sharply increased to levels around 5 percent, and four-

[21] Uncertainty here and in other figures is defined as a square root of the estimated second moments of the fitted distribution of future inflation.

[22] The sample in the original GMR paper ends in 2016.

and five-year average expected inflation increased to levels at around 3 percent, whereas four-to-five-year expected inflation remained at slightly above the 2 percent level in 2022. Those increases occurred amid heightened inflation uncertainty, shown in the bottom panel of Figure 4.

Similar to Figure 3, Figure 5 shows term structures of forward one-year expected inflation rates and forward one-year uncertainty rates in the euro area. Similar to the U.S., relative to the period of 2020-21, the model forecasts a significant upward shift in euro-area forward one-year inflation rates between roughly one and four years from now, and, in the longer term, still upward but much more moderate shift in inflation expectations. The model generates a hump-shaped term structure of one-year forward uncertainty rates, with the hump in the forecast (that corresponds to the highest points of uncertainty in the term structure in January 2023) to be around 2 years from now. Similar to the U.S. model-implied uncertainty rates, the term structure of euro-area inflation uncertainty was mildly upward sloping in 2020-21 but exhibited hump in a term structure for 2022-23, likely reflecting survey respondents' uncertainty over the near-term inflation path.

Table 3 reports summary statistics about average inflation uncertainty rates over different horizons, similarly to expected inflation rates in Table 2. The overall message in this table that inflation uncertainty about medium- and longer-term inflation expectations has increased since the onset of pandemic relative to earlier subperiods of our sample. The bottom panels in Figures 2 and 4 show a substantial increase in near-term inflation uncertainty relative to pandemic years. However, both for the U.S. and euro area, uncertainty about near-term inflation remains lower than during the GFC period. In contrast, uncertainty about longer-term expected inflation is substantially higher than during the GFC, potentially presenting a challenge for monetary policymakers.

4.2 Inflation Anchoring and Tail Probabilities

Panel A of Table 4 shows probabilities for the U.S. CPI inflation being in the range of 1.8 to 2.8 percent for five- and five-to-ten-year horizons. Even though the inflation target is 2 percent, this target applies to the PCE price deflator. It is well known that CPI inflation historically runs about 30 basis points higher than PCE inflation. Therefore, we shifted the PCE $[1, 5, 2.5]$ percent interval 30 basis points to the right and computed the probability of CPI inflation being in the $[1, 8, 2.8]$ percent range. Panel A indicates that the U.S. inflation anchoring probability declined about 5 percentage points from about 50 and 60 percent in the pre-pandemic period to about 45 and 55 percent in the post-pandemic period for five-year and five-to-ten-year, respectively. Panel B of Table 4 reports probabilities for euro-area HICP inflation being in the range of 1.5 to 2.5 percent for five- and four-to-five-year horizons. Similar to the U.S., euro-area anchoring probabilities shifted down about 6 percentage points. This evidence likely reflects some concerns of surveys' respondents about central bankers deviating somewhat from inflation targets. This decline in anchoring probabilities is consistent with the increase in inflation uncertainty reported in Table 3 and shown in Figure 4. Figures 6 and 7 show anchoring probabilities for the U.S. and the euro-area, respectively, along with the NBER/OECD recessions shown as shaded gray vertical bars on the charts. Interestingly, decline in anchoring probabilities appears to often occur in recessions.[23]

Table 5 reports U.S. tail probabilities — namely, probabilities of inflation being higher than 3 percent (upper tails) and being lower than 1 percent (lower tails). As Panel A of Table 5 shows, probability of five-to-ten-year inflation running above 3 percent increased almost 50 percent, from about 6 to about 9 percentage points, from the post-ZLB (2016-19) period to the most recent (2020-23) period. For five-year U.S. inflation, this probability increased even more, almost 70 percent, from about 10 to about 16 percentage points. At the same time, as Panel B of Table 5 shows, the probability of inflation lower than 1 percent was little changed between our subperiods. Figure 8 shows a corresponding time series for U.S. tail probabilities.

Table 6 reports euro-area tail probabilities, similar to Table 5. In contrast to the U.S. probabilities, the upper tail probabilities were little changed. Even though point estimates for both tail probabilities have increased about 2 percentage points, the precision about these estimates has increased as well. As such, in the euro area, probability mass of inflation distributions has shifted away from the center to the tails. This of course, is consistent with an increase in inflation uncertainty discussed in Section 4.1. Figure 9 shows a corresponding time series for euro-area tail probabilities.

4.3 Inflation Risk Premiums

This section reports estimates of inflation risk premiums in the U.S. and the euro area, computed as the difference between market-based measures of inflation compensation and model-implied measures of expected inflation computed at comparable maturities. For the U.S., we use three measures of inflation risk premiums.

The first measure is the TIPS-based inflation compensation (the difference between nominal and TIPS yields of comparable maturities) minus the model-implied measure of inflation expectation of a

[23] We leave for future research this interesting question whether the decline in anchoring probabilities leads recessions or vice versa.

comparable horizon:

$$IRP_{t,n}^{\text{TIPS}} = \underbrace{y_{t,n}^{\text{nom}} - y_{t,n}^{\text{TIPS}}}_{\text{TIPS inflation compensation}} - \mathbb{E}_t \pi_{t,t+n}. \tag{10}$$

The nominal yields $y_{t,n}^{\text{nom}}$ and TIPS yields $y_{t,n}^{\text{TIPS}}$ are fitted yields that are obtained from smoothing methodology of Svensson (1994) model.[24]

It is well known that the TIPS market is a relatively illiquid one compared with the market for nominal U.S. Treasury securities (Grishchenko and Huang, 2013; D'Amico, Kim, and Wei, 2018; Andreasen, Christensen, and Riddell, 2021). Therefore, one needs to properly adjust for relative illiquidity of TIPS that pushes TIPS prices lower and corresponding TIPS yields higher thus lowering the implied TIPS-based inflation compensation measure. We subtract liquidity premiums LP from TIPS rates to adjust them for illiquidity:

$$y_{t,n}^{\text{TIPS, liq}} = y_{t,n}^{\text{TIPS}} - LIQP_{t,n}. \tag{11}$$

As such, we compute our second measure, an adjusted TIPS-based inflation risk premium $IRP_{t,n}^{\text{TIPS, liq}}$ using eq. (11) as:

$$\begin{aligned} IRP_{t,n}^{\text{TIPS, liq}} &= y_{t,n}^{\text{nom}} - y_{t,n}^{\text{TIPS,liq}} - \mathbb{E}_t \pi_{t,t+n} \\ &\equiv y_{t,n}^{\text{nom}} - y_{t,n}^{\text{TIPS}} - \mathbb{E}_t \pi_{t,t+n} + LIQP_{t,n} \equiv IRP_{t,n}^{\text{TIPS}} + LIQP_{t,n}. \end{aligned} \tag{12}$$

To proxy for $LP_{n,t}$, we use two measures. First, we use liquidity premium estimates from the four-factor term structure model of D'Amico, Kim, and Wei (2018, AKW), which are maturity-specific, hence n subscript in the $LP_{n,t}$. As a second measure, we use the fitting error in the two-to-ten-year maturity range of the TIPS Svensson (1994) curve. Hu, Pan, and Wang (2013, HPW) argue that the overall fitting error broadly reflects market functioning and liquidity conditions. In times of relatively well functioning markets, trading is arbitraged away quickly, causing market prices to be close to fundamentals and fitting errors to be small. When markets experience functioning problems, there are fewer arbitrageurs on the markets and thus prices are likely to deviate from fundamentals causing fitting errors to increase. There are pros and cons of both measures. AKW liquidity premium measure is maturity-specific but highly model-dependent whereas HPW liquidity premium measure is not maturity-specific but does not

[24] The TIPS curve between January 1999 and January 2004 has been smoothed using the Nelson and Siegel (1987) methodology rather than the Svensson (1994) one because of an insufficient number of outstanding TIPS securities. See Gürkaynak, Sack, and Wright (2010) for details. For the yield curve data, see `https://www.federalreserve.gov/data/yield-curve-models.htm`.

depend on model assumptions. Figure 13 show the AKW and HPW premium time series in our sample. Both premium proxies spiked around the same time during the GFC and at the onset of the COVID-19 pandemic. However, the fitting error stayed around its usual historical level of 5 basis points and spiked briefly at the end of 2022, whereas the AKW liquidity premium has turned negative for both five- and five-to-ten-year horizons. The latter declined as low as below negative 1 percentage point for the five-year horizon in early 2022 before it rebounded to levels close to zero in late 2022 through early 2023.

A third measure of inflation risk premium is based on inflation swaps. We subtract our model-based measure of inflation expectations from the inflation swap rate $s_{t,n}$ of comparable horizons:

$$IRP^{\text{Swap}}_{t,n} = s_{t,n} - \mathbb{E}_t \pi_{t,t+n}. \tag{13}$$

Inflation swap rates are over-the-counter products and therefore less affected by the liquidity issues. However, this market at bit more recent that the TIPS market. Its sample starts in June 2004 only.

We report summary statistics (means and standard deviations) for the U.S. inflation risk premiums (10) and (13) in Table 7. Interestingly, as Panel A of Table 7 shows, five-year TIPS-based estimates of inflation risk premiums are negative in almost all subperiods. However, five-to-ten-year inflation risk premiums are not statistically different from zero (8 and 10 basis points with standard deviations of 38 and 34 basis points, respectively), a result broadly consistent with estimates in Grishchenko and Huang (2013). Swap-based inflation risk premiums are either less negative (for a five-year horizon) or positive (for a five-to-ten-year horizon) albeit with higher standard errors for the post-ZLB period and the period since the onset of the COVID-19 pandemic.

Additionally, Table 8 reports summary statistics for liquidity-adjusted inflation risk premiums (12) for two proxies of $LP_{t,n}$, AKW in Panel A and HPW in Panel B, respectively. Interestingly, AKW liquidity adjustment does not result in higher inflation risk premium across all subperiods, likely due to AKW liquidity premium turning negative, most prominently, after the onset of the COVID-19 pandemic in 2020 and, to a lesser extent, in 2012-13. An alternative HPW liquidity-inflation risk premiums are uniformly less negative across all subperiods due to the fact that the TIPS fitting error that we use for the second adjustment is always positive. Despite these differences, the broad message from Tables 7 and 8 is that longer-term (five-to-ten-year) inflation risk premiums have stayed mainly positive during our entire sample period (1999-2023), declined during the post-ZLB subperiod (2016-2019), and increased again since the onset of the COVID-19 pandemic. Figures 10 and 11 plot time series of these inflation risk premiums.

Finally, for this section, we report summary statistics for swap-based inflation risk premiums (13) for the euro area, in Table 9. Figure 12 shows time series of euro-area inflation risk premiums. We find that euro-area inflation risk premiums are negative in our sample almost everywhere. One of the potential explanations is the liquidity premium in the euro-area inflation swaps that maybe embedded in their quotes.

4.4 Regression Results

4.4.1 Inflation Expectations, Uncertainty, and Risk Premiums

Next, we examine the effect of time variation in tail probability distributions of future inflation on expected inflation, inflation uncertainty, and inflation risk premiums. Specifically, Table 10 reports the following regression results:

$$\mathbb{E}_t(\pi_{t,t+n}) = \alpha + \beta_{UPT} UPT_{t,n} + \beta_{LPT} LPT_{t,n} + \epsilon_{t+n}, \tag{14}$$

where $UPT_{t,n}$ is the model-implied probability of future inflation increasing more than 3 percent (Upper Tail Probability) and $LPT_{t,n}$ is the model-implied probability of future inflation declining below 1 percent (Lower Tail Probability). We report both the univariate and multivariate results. For the U.S. (Panel A), we report results for five- and five-to-ten-year horizons; and for the euro area (Panel B), we report results for five- and four-to-five-year horizons. Both β_{UPT} and β_{LPT} coefficients are significant at the 1 percent level.[25] However, R^2 is higher for longer-horizon specifications, indicating that variation in inflation tails has more explanatory power for variation in longer-term inflation expectations, both for the U.S. and the euro area.

Table 11 similarly reports the results of the following regression:

$$UNC_t(\pi_{t,t+n}) = \alpha + \beta_{UPT} UPT_{t,n} + \beta_{LPT} LPT_{t,n} + \epsilon_{t+n}, \tag{15}$$

where inflation uncertainty $UNC_t(\pi_{t,t+n})$ is defined as a square root of the GMR model-implied inflation variance $\mathbb{V}ar_t(\pi_{t,t+n})$. The R^2's are high and they are much higher for upper tails used as an explanatory variable in regression (15) than for lower tails in the U.S. (Panel A). This suggests that an increase in

[25]Standard errors in this and future tables are corrected for three-lag heteroscedasticity following Newey and West (1987b, NW).

upside inflation risk matters more for an increase in uncertainty than an increase in downside inflation risk. Interestingly, this result is flipped for the euro area, where variation in lower tails has higher explanatory power than variation in upper tails.

Tables 12 and 13 report regression results of inflation risk premiums in the U.S. and inflation risk premiums in the euro area , respectively:

$$IRP_{t,t+n} = \alpha + \beta_{UP}UP_{t,n} + \beta_{LP}LP_{t,n} + \epsilon_{t+n}, \tag{16}$$

For the U.S. (Table 12), inflation tails explain more variation in swap-based than in unadjusted TIPS-based inflation risk premiums, and upper tails have more explanatory power. For the euro area (Table 13), however, lower tails appear to be more important in explaining variation in inflation risk premiums. These results are highly preliminary and subject to change. However, one main finding emerges from these four tables. Both upper and lower tail probabilities that reflect upside and downside risks about future inflation are important in explaining time variation in those measures for any considered horizon, any market measure of inflation compensation and either liquidity adjustment.

Note that regressions (14), (15), and (16) are contemporaneous ones. We also have run corresponding predictive regressions where we regressed expected inflation, inflation uncertainty, and inflation risk premiums on lagged tail probabilities. The results are broadly similar to the contemporaneous regressions' results and reported in Appendix A in Tables A.1 through A.6.

4.4.2 Inflation Tail Probabilities

Next, we explore what potential factors predict time variation in upper and lower tail probabilities, UPT and LPT. We use several exogenous factors related to various measures of uncertainty. It stands to reason that the wider the conditional distribution over a certain macroeconomic series, the more uncertain forecasters are (for example, Zarnowitz and Lambros, 1987; Grishchenko, Mouabbi, and Renne, 2019). Naturally, wider distributions imply more probability mass at the tails of the distribution, leading to higher values of inflation tails, in our case. We explore which factors explain this kind of uncertainty. The first set are the econometric measures developed in Jurado, Ludvigson, and Ng (2015, JLN) and related to macroeconomic, real activity, and financial uncertainty measures, MU_t, RU_t, and FU_t, respectively (sometimes referred to as JLN measures for brevity). JLN have constructed these uncertainty measures for $h = 1,\ 3,$ and 12 months ahead, and we included each of these horizon-specific measures in our regressions. JLN uncertainty measures are defined as conditional volatility of an unexplained (surprise) component of various macroeconomic and financial series, average across series. Naturally, higher conditional volatility of the surprise component reflects higher uncertainty about macroeconomic, real activity, and financial data prints. Figure 14 shows JLN measures whose increases are associated with the NBER recessions (shown by grey shaded bars on the charts). The second type of uncertainty is the Economic Policy Uncertainty (EPU) developed by Baker, Bloom, and Davis (2016). The EPU index reflects the frequency of articles in 1o leading U.S. newspapers that contain the following trio of terms: "economic" or "economy"; "uncertain" or "uncertainty"; and and one or more of "Congress," "deficit," "Federal Reserve," "legislation," "regulation," or "White House." Higher EPU values are associated with higher uncertainty regarding (macro-)economic outcomes. The third type of uncertainty is related to geopolitical risk. Namely, we use the Geopolitical Risk index (GPR) developed by Caldara and Iacoviello (2022). The index reflects the frequency of newspaper articles discussing adverse geopolitical events. In general, higher values of the GPR index are associated with higher current intensity of negative events (for example, more wars), higher probability of negative events in the future, and higher expected intensity of future negative events. Increases in the U.S. GPR measure, shown in the top left chart on Figure 14 or in the euro-area GPR measure, shown in the top chart on Figure 15, are not necessarily associated with either NBER or OECD recessions, respectively, while increases in the U.S. EPU measure, shown in the top right chart of Figure 14 or in the euro-area EPU measure, shown in the bottom chart of Figure 15, tend to coincide with recessions in respective economic areas, in general. With that in mind, we run the following regressions:

$$TP^i_{t+h,n} = \alpha + \beta_1 MU^h_t + \beta_2 RU^h_t + \beta_3 FU^h_t + \beta_4 EPU^i_t + \beta_5 GPR^i_t + \epsilon_{t+h}, \tag{17}$$

for economic area i where $TP^i_{t,n} = \{UTP^i_{t,n}, LTP^i_{t,n}\}$ and $i = \{\mathrm{US}, \mathrm{EA}\}$. We run predictive regressions (17) for $h = 1$, 3, 12 months ahead.[26]

We report results for U.S. upper inflation tails for five- and five-to-ten-year horizons in Tables 14 and 15, and for U.S. lower inflation tails — in Tables 16 and 17 for the same horizons. We find that, on balance, higher EPU predicts lower probability of higher inflation (that is, future inflation being higher than 3 percent), while higher GPR predicts increases in upper inflation tail probabilities. The EPU and GPR coefficients are significant on 1 and 5 percent level, both in univariate and multivariate regressions,

[26]We include MU^h_t, RU^h_t, FU^h_t only in the regressions related to U.S. tail probabilities as such measures are not available for the euro area.

with the exception of the case when we run regressions of the 12-month ahead upper inflation tails on the current GPR ($h = 12$-month case reported in Panels C of these two tables.) Interestingly, JLN measures are never significant in univariate regressions, but become significant in multivariate regressions. The results are similar for lower inflation tail probability regressions, but with the opposite sign. Higher EPU indicates higher probability of lower inflation (that is, inflation falling under the 1 percent), with coefficients being significant mostly at the 1 percent level (with the exception of one case of $h = 12$, five-year horizon when the coefficient has 5-percent level of significance). Similarly for upper tail regressions, JLN measures are not significant with the exception of RU_{t+1} and RU_{t+3} variables that are significant explaining the variation of the five-to-ten-year inflation probability tail. Also, similarly to upper tail regressions, $MU, RU,$ and FU become significant in multivariate regressions.

For the euro area, as reported in Tables 18 and 19 for 5- and four-to-five-year horizons, higher economic policy uncertainty leads to higher probability of either higher or lower future inflation outcomes, in general. The results appear to be stronger for five-year horizon than for four-to-five-year horizon. We interpret this as higher economic policy uncertainty, in general, increases uncertainty about future inflation as measured by wider probability distribution over future inflation, with increases in tail probabilities on both sides.[27] Interestingly, in contrast, to the results for the U.S., geopolitical risk does not explain variation in inflation tail probabilities in the euro area.

5 Conclusion

In the past few years since the outset of COVID-19 pandemic, inflation has been running well above the relevant targets of central banks around the world. Assessing future expected inflation is a high priority for central banking economists and monetary policy makers around the world in the very near future. In this paper we focused on measuring the probabilities of extreme inflation outcomes and on using these probabilities to forecast future inflation movements. To that end, we have used the state-space model developed in Grishchenko, Mouabbi, and Renne (2019) that incorporates information from the large set of surveys of professional forecasters that report inflation consensus forecasts and some of which provide distribution about future inflation outcomes. These surveys relate to inflation forecasts of the United States and euro area. Due to affine properties of the model, the term structures of inflation expectations,

[27]Note that, in general, our model does not address the skewness of inflation distribution because of modeling assumptions that the shocks in the model follow a symmetrical autoregressive gamma process. Relaxing this assumption is an area for future research.

inflation uncertainty, as well as probabilities of future inflation for any range of inflation outcomes have been computed in closed form at any horizon. We find that, since the onset of the COVID-19 pandemic, inflation expectations increased materially amid heightened uncertainty about future inflation; likelihood of five-to-ten-years-ahead inflation outcomes in the U.S. and the euro area surpassing 3 percent reached about 15 and 13 percent in the middle of 2022, respectively, increasing from near zero levels. We also find that such an increase in the right tail of the distribution over future inflation outcomes drives an increase in inflation expectations and inflation risk premiums. Lastly, our results suggest that the Baker, Bloom, and Davis (2016) measure of economic policy uncertainty have some predictive content for both the U.S. and the euro area tail probabilities and that the geopolitical risk measures developed by Caldara and Iacoviello (2022) have some predictive content for the U.S. but not for the euro area.

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Table 1: Summary of the Survey Data

Survey	Horizon	Forecast	Index	Freq.	Sample
Panel A: Surveys of inflation forecasts in the United States					
US SPF	$\bar{\pi}_{t,t+12}$	Density	GDP deflator	Quarterly	1999:Q1 - 2022:Q4
US SPF	$\bar{\pi}_{t,t+15}$	Density	GDP deflator	Quarterly	1999:Q1 - 2022:Q4
US SPF	$\bar{\pi}_{t,t+18}$	Density	GDP deflator	Quarterly	1999:Q1 - 2022:Q4
US SPF	$\bar{\pi}_{t,t+21}$	Density	GDP deflator	Quarterly	1999:Q1 - 2022:Q4
US SPF	$\bar{\pi}_{t,t+24}$	Density	GDP deflator	Quarterly	1999:Q1 - 2022:Q4
US SPF	$\pi_{t,t+60}$	Point estimates	CPI	Quarterly	2005:Q3 - 2022:Q4
BCFF, BCEI	$\pi_{t+60,t+120}$	Point estimates	CPI	4/year	3/1999 - 1/2023
US SPD	$\pi_{t,t+60}$	Density	CPI	FOMC	12/2014 - 1/2023
US SPD	$\pi_{t+60,t+120}$	Density	CPI	FOMC	3/2007 - 1/2023
US CES	$\pi_{t,t+12}$	Point estimates	CPI	Monthly	1/1999 - 1/2023
Panel B: Surveys of inflation forecasts in the Euro area					
ECB SPF	$\pi_{t,t+12}$	Density	HICP	Quarterly	1999:Q1 - 2022:Q4
ECB SPF	$\pi_{t+12,t+24}$	Density	HICP	Quarterly	1999:Q1 - 2022:Q4
ECB SPF	$\pi_{t,t+60}$	Density	HICP	Quarterly	1999:Q1 - 2022:Q4
EA CES	$\pi_{t+60,t+120}$	Point estimates	HICP	Semiannual	4/2003 - 1/2023

Note: This table summarizes inflation forecast variables from the U.S. and euro-area surveys used in the study. The abbreviations of the surveys used in the table are as follows: US-SPF (Survey of Professional Forecasters conducted by the Federal Reserve Bank of Philadelphia), BCFF and BCEI (Blue Chip Financial Forecasts and Blue Chip Economic Indicators, respectively), US SPD (Survey of Primary Dealers conducted by the Federal Reserve Bank of New York), CES (Consensus Economics Survey conducted by Consensus Economics), and ECB SPF (Survey of Professional Forecasters conducted by the European Central Bank).

Table 2: Inflation Expectations in the U.S. and Euro Area

Sample period	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Panel A: United States								
	1-year		5-year		10-year		5-to-10-year	
Full	2.27	0.71	2.29	0.32	2.30	0.22	2.31	0.19
Pre-GFC	2.35	0.39	2.44	0.16	2.47	0.09	2.50	0.09
GFC and ZLB	1.80	0.42	2.04	0.15	2.14	0.09	2.25	0.12
Post-ZLB	2.17	0.22	2.11	0.09	2.10	0.05	2.09	0.03
COVID-19	3.27	1.29	2.59	0.59	2.37	0.34	2.14	0.10
Panel B: Euro Area								
	1-year		4-year		5-year		4-to-5-year	
Full	1.87	0.62	1.87	0.28	1.87	0.24	1.88	0.10
Pre-GFC	1.93	0.24	1.91	0.13	1.91	0.11	1.89	0.07
GFC and ZLB	1.66	0.36	1.81	0.17	1.83	0.15	1.92	0.07
Post-ZLB	1.59	0.25	1.71	0.12	1.73	0.10	1.80	0.06
COVID-19	2.53	1.41	2.08	0.65	2.03	0.56	1.82	0.18

Note: This table reports means and standard deviations of the Grishchenko, Mouabbi, and Renne (2019) model-implied inflation rates in the U.S. (Panel A) and in the euro area (Panel B) for December 1998–January 2023 (full sample period) and several subsample periods: December 1998–December 2008, a period that precedes the Global Financial Crisis (GFC); January 2009–December 2015, a period that encompasses the GFC and the zero-lower-bound (ZLB) periods; January 2016–February 2020, a period that follows the ZLB period; and March 2020–January 2023, a period that includes the onset of the COVID-19 pandemic and the years following. Reported summary statistics are for the average inflation rates at one-, five-, ten-, and five-to-ten-year horizons for the U.S. and at one-, four-, five-, and four-to-five-year horizons for the euro area. The surveys' data are from December 1998 to January 2023. The frequency is monthly.

Table 3: Inflation Uncertainty in the U.S. and Euro Area

Sample period	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Panel A: United States								
	1-year		5-year		10-year		5-to-10-year	
Full	0.82	0.15	0.79	0.07	0.70	0.07	0.58	0.14
Pre-GFC	0.91	0.05	0.75	0.03	0.62	0.02	0.44	0.04
GFC and ZLB	0.86	0.16	0.85	0.06	0.75	0.02	0.64	0.10
Post-ZLB	0.62	0.02	0.74	0.02	0.73	0.02	0.72	0.01
COVID-19	0.74	0.12	0.84	0.08	0.79	0.05	0.74	0.02
Panel B: Euro Area								
	1-year		4-year		5-year		4-to-5-year	
Full	0.82	0.15	0.59	0.09	0.59	0.09	0.60	0.08
Pre-GFC	0.91	0.05	0.49	0.03	0.49	0.03	0.51	0.02
GFC and ZLB	0.86	0.16	0.66	0.02	0.66	0.02	0.65	0.03
Post-ZLB	0.62	0.02	0.63	0.02	0.64	0.02	0.65	0.01
COVID-19	0.74	0.12	0.71	0.05	0.71	0.05	0.70	0.03

Note: This table reports means and standard deviations of the Grishchenko, Mouabbi, and Renne (2019) model-implied times series estimates of inflation uncertainty in the in the U.S. (Panel A) and in the euro area (Panel B) for December 1998–January 2023 (full sample period) and several subsample periods: December 1998–December 2008, a period that precedes the Global Financial Crisis (GFC); January 2009–December 2015, a period that encompasses the GFC and the zero-lower-bound (ZLB) periods; January 2016–February 2020, a period that follows the ZLB period; and March 2020–January 2023, a period that includes the onset of the COVID-19 pandemic and the years following. Reported summary statistics is for average inflation uncertainty for one-, five-, ten-, and five-to-ten-year horizons. The surveys' data are from December 1998 to January 2023. The frequency is monthly.

Table 4: Inflation Anchoring Probabilities in the U.S. and Euro Area

	Mean	SD	Mean	SD
Panel A: United States				
	5-year		5-to-10-year	
Full	49.19	3.28	60.18	4.40
Pre-GFC	51.59	2.18	63.26	4.68
GFC and ZLB	46.69	1.88	58.76	1.35
Post-ZLB	49.96	1.40	58.33	1.71
COVID-19	45.81	3.82	55.59	3.62
Panel B: Euro Area				
	5-year		4-to-5-year	
Full	60.22	6.67	69.22	4.48
Pre-GFC	67.29	2.50	73.21	2.72
GFC and ZLB	56.54	1.63	67.73	1.23
Post-ZLB	56.02	2.47	67.21	2.47
COVID-19	50.62	2.87	61.89	2.99

Note: This table reports means and standard deviations of estimates of inflation anchoring probabilities in the U.S. (Panel A) and in the euro area (Panel B) for December 1998–January 2023 (full sample period) and several subsample periods: December 1998–December 2008, a period that precedes the Global Financial Crisis (GFC); January 2009–December 2015, a period that encompasses the GFC and the zero-lower-bound (ZLB) periods; January 2016–February 2020, a period that follows the ZLB period; and March 2020–January 2023, a period that includes the onset of the COVID-19 pandemic and the years following. For the U.S. and the euro area, anchoring probabilities correspond to CPI inflation and HICP inflation being in the 1.8-to-2.8 and 1.5-to-2.5 percent range, respectively. Reported means and standard deviations for the U.S. are for five- and five-to-ten-year horizons; for EA — for five- and four-to-five-year horizons. The estimates are implied by the Grishchenko, Mouabbi, and Renne (2019) state-space survey-based model. Probabilities are reported in percentage points. The surveys' data are from December 1998 to January 2023. The frequency is monthly.

Table 5: Inflation Tail Probabilities in the U.S.

Sample period	Mean	SD	Mean	SD
Panel A: Inflation higher than 3 percent				
	5-year		5-to-10-year	
Full	17.64	6.13	12.60	5.71
Pre-GFC	22.46	3.40	17.12	4.28
GFC and ZLB	15.71	4.16	11.33	4.29
Post-ZLB	9.77	0.76	6.01	0.57
COVID-19	16.81	7.18	9.47	4.03
Panel B: Inflation lower than 1 percent				
	5-year		5-to-10-year	
Full	5.23	2.26	2.67	1.73
Pre-GFC	2.82	0.63	0.85	0.28
GFC and ZLB	6.98	0.84	3.50	0.85
Post-ZLB	6.89	0.66	4.24	0.47
COVID-19	6.96	2.09	4.75	1.21

Note: This table reports means and standard deviations of the times series estimates of probabilities of inflation being higher than three percent (Panel A) and lower than one percent (Panel B) in the U.S. for December 1998 to January 2023 (full sample period), and several subsample periods: December 1998–December 2008, a period that precedes the Global Financial Crisis (GFC); January 2009–December 2015, a period that encompasses the GFC and the zero-lower-bound (ZLB) periods; January 2016–February 2020, a period that follows the ZLB period; and March 2020–January 2023, a period that includes the onset of the COVID-19 pandemic and the years following. Reported means and standard deviations for 5- and five-to-ten-year horizons. Estimates are implied by the Grishchenko, Mouabbi, and Renne (2019) state-space survey-based model. Probabilities are reported in percentage points. The surveys' data are from December 1998 to January 2023. The frequency is monthly.

Table 6: Inflation Tail Probabilities in the Euro Area

Sample period	Mean	SD	Mean	SD
Panel A: Higher than 3 percent				
	5-year		4-to-5-year	
Full	3.53	2.34	2.40	1.49
Pre-GFC	1.35	0.58	1.43	0.79
GFC and ZLB	5.46	0.95	3.72	1.01
Post-ZLB	3.78	0.37	2.18	0.61
COVID-19	6.07	3.18	2.90	2.37
Panel B: Lower than 1 percent				
	5-year		4-to-5-year	
Full	7.03	3.12	3.41	1.79
Pre-GFC	4.22	1.26	2.36	1.02
GFC and ZLB	7.75	1.36	3.17	0.88
Post-ZLB	9.57	1.67	4.47	1.26
COVID-19	11.37	3.22	6.13	2.45

Note: This table reports means and standard deviations of the times series estimates of probabilities of inflation being higher than three percent (Panel A) and lower than one percent (Panel B) in the Euro area for the full sample period, December 1998 to January 2023, and several subsample periods: December 1998–December 2008, a period that precedes the Global Financial Crisis (GFC); January 2009–December 2015, a period that encompasses the GFC and the zero-lower-bound (ZLB) periods; January 2016–February 2020, a period that follows the ZLB period; and March 2020–January 2023, a period that includes the onset of the COVID-19 pandemic and the years following. Reported means and standard deviations for 5- and five-to-ten-year horizons. Estimates are implied by the Grishchenko, Mouabbi, and Renne (2019) state-space survey-based model. Probabilities are reported in percentage points. The surveys' data are from December 1998 to January 2023. The frequency is monthly.

Table 7: Inflation Risk Premium in the U.S.

Sample period	Mean	SD	Mean	SD
Panel A: TIPS-Based				
	5-year		5-to-10-year	
Full	-0.42	0.47	0.08	0.38
Pre-GFC	-0.51	0.54	0.10	0.34
GFC and ZLB	-0.31	0.40	0.34	0.34
Post-ZLB	-0.36	-0.26	0.19	0.22
COVID-19	-0.34	-0.07	0.42	0.29
Panel B: Swaps-Based				
	5-year		5-to-10-year	
Full	-0.06	0.35	0.35	0.30
Pre-GFC	0.10	0.41	0.42	0.18
GFC and ZLB	-0.01	0.26	0.56	0.28
Post-ZLB	-0.17	0.09	0.19	0.19
COVID-19	-0.16	0.18	0.37	0.22

Note: This table reports means and standard deviations of inflation risk premiums in the United States defined as the difference between comparable-maturity Treasury Inflation-Protected Securities (TIPS)-based inflation compensation (Panel A) or inflation swaps rates (Panel B) and inflation expectations implied by the Grishchenko, Mouabbi, and Renne (2019) state-space survey-based model, for five- and five-to-ten-year ahead horizons. The sample period for TIPS-Based inflation risk premiums (Panel A) is from January 4, 1999 to January 31, 2023. The sample period for swaps-based inflation risk premiums (Panel B) is from August 16, 2004, to January 31, 2023. The frequency is daily.

Table 8: Liquidity-Adjusted Inflation Risk Premium in the U.S.

Sample period	Mean	SD	Mean	SD
Panel A: Liquidity Premium				
	5-year		5-to-10-year	
Full	0.14	0.45	0.32	0.33
Pre-GFC	0.44	0.32	0.52	0.26
GFC and ZLB	0.13	0.32	0.38	0.26
Post-ZLB	0.01	0.11	0.03	0.20
COVID-19	-0.65	0.29	-0.08	0.16
Panel B: TIPS Fitting Error				
	5-year		5-to-10-year	
Full	-0.38	0.46	0.12	0.38
Pre-GFC	-0.49	0.51	0.12	0.34
GFC and ZLB	-0.26	0.38	0.40	0.33
Post-ZLB	-0.32	0.19	-0.22	0.22
COVID-19	-0.30	0.42	-0.03	0.29

Note: This table reports means and standard deviations of inflation risk premiums in the United States adjusted for liquidity. The premiums are defined as the difference between Treasury Inflation-Protected Securities (TIPS)-based inflation compensation adjusted for liquidity and inflation expectations implied by the Grishchenko, Mouabbi, and Renne (2019) state-space survey-based model. The liquidity adjustment uses either the D'Amico, Kim, and Wei (2018) model (Panel A) or the TIPS fitting error computed by following the Hu, Pan, and Wang (2013) methodology (Panel B). Liquidity-adjusted inflation risk premiums are shown for five- and five-to-ten-year ahead horizons. The sample period is from January 4, 1999, to January 31, 2023. The frequency is daily.

Table 9: Inflation Risk Premium in the Euro Area

Sample period	Mean	SD	Mean	SD
	5-year		4-to-5-year	
Full	-0.24	0.41	-0.11	0.41
Pre-GFC	0.20	0.21	0.31	0.15
GFC and ZLB	-0.27	0.32	-0.06	0.32
Post-ZLB	-0.61	0.16	-0.56	0.19
COVID-19	-0.27	0.44	-0.24	0.36

Note: This table reports means and standard deviations of inflation risk premiums in the euro area defined as the difference between comparable-maturity euro-area inflation swap rates and inflation expectations in the euro area implied by the Grishchenko, Mouabbi, and Renne (2019) state-space survey-based model. Inflation risk premiums are shown for five- and four-to-five-year ahead horizons. The sample period is from June 22, 2004, to January 31, 2023. The frequency is daily.

Table 10: Expected Inflation Regressions

	5-year	5-to-10-year	5-year	5-to-10-year	5-year	5-to-10-year
Panel A: United States						
Upper Tail Probability	0.033	**0.032**			0.023	**0.019**
	(0.027)	(0.002)			(0.075)	(0.001)
Lower Tail Probability			**-0.083**	**-0.103**	-0.035	**-0.052**
			(0.020)	(0.015)	(0.162)	(0.006)
Adj. R2	0.39	0.91	0.33	0.88	0.41	0.99
N.Obs.	290	290	290	290	290	290
	5-year	4-to-5-year	5-year	4-to-5-year	5-year	4-to-5-year
Panel B: Euro Area						
Upper Tail Probability	0.041	0.048*			0.079	0.035
	(0.251)	(0.027)			(0.181)	(0.022)
Lower Tail Probability			-0.035*	**-0.045**	-0.062	**-0.037**
			(0.021)	(0.006)	(0.047)	(0.007)
Adj. R2	0.16	0.53	0.20	0.69	0.67	0.95
N.Obs.	290	290	290	290	290	290

Note: This tables reports regression results of expected inflation regressions for the U.S. (Panel A) and the euro area (Panel B) to inflation tail probabilities of comparable horizons. The right-hand side variables are defined as follows: The *upper tail probability* represents the probability of inflation being higher than 3 percent; the *lower tail probability* represents the probability of inflation being lower than 1 percent. Results are shown for five- and five-to-ten-year horizons for the U.S. and for five- and four-to-five-year horizons for the euro area. Expected inflation and tail probabilities are used in the regressions at comparable horizons. Standard errors reported in parentheses below coefficients estimates are corrected for heteroscedasticity with three lags following the Newey and West (1987a) methodology. */bolded coefficients indicate coefficients significant at the 10 and 1 percent level, respectively. The sample period is from December 1998 to January 2023. The frequency is monthly. Source: authors' calculations.

Table 11: Inflation Uncertainty Regressions

	5-year	5-to-10-year	5-year	5-to-10-year	5-year	5-to-10-year
Panel A: United States						
Upper Tail Probability	0.002	**-0.018**			**0.014**	-0.001
	(0.004)	(0.002)			(0.002)	(0.005)
Lower Tail Probability			0.013**	**0.071**	**0.042**	**0.069**
			(0.006)	(0.015)	(0.010)	(0.025)
Adj. R2	0.03	0.54	0.20	0.80	0.84	0.80
N.Obs.	290	290	290	290	290	290
	5-year	4-to-5-year	5-year	4-to-5-year	5-year	4-to-5-year
Panel B: Euro Area						
Upper Tail Probability	**0.035**	0.030			**0.027**	**0.043**
	(0.010)	(0.024)			(0.003)	(0.003)
Lower Tail Probability			0.023**	0.026	**0.013**	**0.036**
			(0.010)	(0.112)	(0.001)	(0.009)
Adj. R2	0.82	0.32	0.60	0.34	0.99	0.93
N.Obs.	290	290	290	290	290	290

Note: This tables reports regression results of expected inflation regressions for the U.S. (Panel A) and the euro area (Panel B) to inflation tail probabilities of comparable horizons. The right-hand side variables are defined as follows: The *upper tail* represents the probability of inflation being higher than 3 percent; the *lower tail* represents the probability of inflation being lower than 1 percent. Results are shown for the U.S. for five- and five-to-ten-year horizons, and for the euro area for five- and four-to-five-year horizons. Inflation uncertainty and tail probabilities are used in the regressions at comparable horizons. Standard errors reported in parentheses below coefficients estimates are corrected for heteroscedasticity with three lags following the Newey and West (1987a) methodology. **/bolded coefficients indicate coefficients significant at the 5 and 1 percent level, respectively. The sample period is from December 1998 to January 2023. The frequency is monthly. Source: authors' calculations.

Table 12: Inflation Risk Premium Regressions: U.S.

	5-year	5-to-10-year	5-year	5-to-10-year	5-year	5-to-10-year
Panel A: Swap-based inflation risk premiums						
Upper Tail Probability	0.005	0.023*			-0.011	0.017*
	(0.011)	(0.012)			(0.008)	(0.010)
Lower Tail Probability			-0.050*	-0.059	-0.070**	-0.022
			(0.027)	(0.041)	(0.028)	(0.051)
Adj. R2	0.00	0.11	0.07	0.09	0.08	0.12
N.Obs.	220	220	220	220	220	220
Panel B: TIPS-based inflation risk premiums						
Upper Tail Probability	-0.022*	0.009			**-0.034**	0.000
	(0.012)	(0.015)			(0.011)	(0.015)
Lower Tail Probability			0.028	-0.035	-0.041	-0.035
			(0.035)	(0.055)	(0.034)	(0.069)
Adj. R2	0.07	0.01	0.01	0.02	0.08	0.02
N.Obs.	289	289	289	289	289	289
Panel C: AKW-liquidity-adjusted inflation risk premiums						
Upper Tail Probability	0.022	**0.029**			-0.017	0.000
	(0.031)	(0.008)			(0.042)	(0.011)
Lower Tail Probability			**-0.100**	**-0.118**	-0.135	**-0.117**
			(0.030)	(0.020)	(0.095)	(0.032)
Adj. R2	0.08	0.24	0.25	0.37	0.27	0.36
N.Obs.	289	289	289	289	289	289
Panel D: HPW-liquidity-adjusted inflation risk premiums						
Upper Tail Probability	-0.023**	0.008			**-0.033**	0.001
	(0.02)	(0.015)			(0.011)	(0.016)
Lower Tail Probability			0.035	-0.029	-0.033	-0.026
			(0.036)	(0.057)	(0.035)	(0.072)
Adj. R2	0.08	0.01	0.02	0.01	0.09	0.01
N.Obs.	289	289	289	289	289	289

Note: This table reports regression results of U.S. inflation risk premium regressions for four proxies of inflation risk premiums. Panels A and B report regression results for swap- and Treasury Inflation-Protected Securities (TIPS)-based inflation risk premium, respectively. Panels C and D report regression results liquidity-adjusted TIPS-based risk premiums, using D'Amico, Kim, and Wei (2018) liquidity adjustment and Hu, Pan, and Wang (2013) liquidity adjustment, respectively. The right-hand side variables are defined as follows: The *upper tail probability* represents the probability of inflation being higher than 3 percent; the *lower tail probability* represents the probability of inflation being lower than 1 percent. Inflation risk premiums and tail probabilities are used in the regressions at comparable horizons. Standard errors reported in parentheses below coefficients estimates are corrected for heteroscedasticity with three lags following the Newey and West (1987a) methodology. */**/bolded coefficients indicate coefficients significant at the 10, 5, and 1 percent level, respectively. The sample period is from January 1999 to January 2023. The frequency is monthly. Source: Bloomberg, Board of Governors of the Federal Reserve System, and authors' calculations.

Table 13: Inflation Risk Premium Regressions: Euro Area

	5-year	4-to-5-year	5-year	4-to-5-year	5-year	4-to-5-year
Upper Tail Probability	-0.028	0.060			0.020	-0.023
	(0.053)	(0.058)			(0.036)	(0.036)
Lower Tail Probability			**-0.089**	**-0.140**	**-0.094**	**-0.146**
			(0.016)	(0.030)	(0.023)	(0.027)
Adj. R2	0.02	0.04	0.49	0.47	0.50	0.47
N.Obs.	224	224	224	224	224	224

Note: This table reports regression results of euro-area swap-based inflation risk premiums regressions for the euro area to inflation tail probabilities of comparable horizons. The right-hand side variables are defined as follows: The *upper tail probability* represents the probability of inflation being higher than 3 percent; the *lower tail probability* represents the probability of inflation being lower than 1 percent. Inflation risk premiums and tail probabilities are used in the regressions at comparable horizons. Standard errors reported in parentheses below coefficients estimates are corrected for heteroscedasticity with three lags following the Newey and West (1987a) methodology. */**/bolded coefficients indicate coefficients significant at the 10, 5, and 1 percent level, respectively. The sample period is from June 2004 to January 2023. The frequency is monthly. Source: Bloomberg, Board of Governors of the Federal Reserve System, and authors' calculations.

Table 14: 5-year Upper Tail Probability Regressions: U.S.

	(1)	(2)	(3)	(4)	(5)	(6)
Panel A: $h = 1$-month						
MU	7.05					45.8*
	(29.3)					(27.2)
RU		-7.43				-39.1**
		(17.2)				(19.4)
FU			8.72			7.37
			(12.7)			(7.94)
EPU				**-0.028**		**-0.033**
				(0.007)		(0.009)
GPR-USA					1.19**	1.06**
					(0.504)	(0.521)
Adj. R2	0.02	0.02	0.07	0.08	0.07	0.49
N.Obs.	289	289	289	289	289	289
Panel B: $h = 3$-month						
MU	10.2					44.4*
	(31.1)					(25.3)
RU		-7.11				-42.0**
		(27.2)				(20.4)
FU			12.3			11.0
			(18.9)			(10.6)
EPU				**-0.027**		**-0.033**
				(0.008)		(0.009)
GPR-USA					1.15**	1.07
					(0.542)	(0.521)
Adj. R2	0.03	0.01	0.09	0.08	0.06	0.50
N.Obs.	287	287	287	287	287	287
Panel C: $h = 12$-month						
MU	33.7					54.8
	(49.3)					(41.2)
RU		0.463				-42.5
		(83.8)				(66.2)
FU			47.9			46.3*
			(50.7)			(24.8)
EPU				-0.023**		-0.042**
				(0.010)		(0.017)
GPR-USA					0.452	0.67
					(0.72)	(0.424)
Adj. R2	0.10	0.00	0.35	0.05	0.01	0.45
N.Obs.	278	278	278	278	278	278

Note: This table reports regression results of U.S. probability of 5-year average inflation surpassing 3 percent (upper tail probability) on the following explanatory variables: Macroeconomic Uncertainty (MU), Real Economic Uncertainty (RU), and Financial Uncertainty (FU) measures of Jurado, Ludvigson, and Ng (2015), Economic Policy Uncertainty (EPU) of Baker, Bloom, and Davis (2016), and Geopolitical Risk (GPR) measure of Caldara and Iacoviello (2022). Panels A, B, and C report regression results for $h = 1$, 3, 12 lags in independent variables. Standard errors in Panels A, B, and C are corrected for heteroskedasticity with lags $h = 1, 3, 12$, respectively, that are computed by following the Newey and West (1987a) methodology. */**/bolded coefficients indicate coefficients significant at the 10, 5, and 1 percent level, respectively. The sample period is from January 1999 to January 2023. The frequency is monthly.

Table 15: 5-Year, 5-Years-Ahead Upper Tail Probability Regressions: U.S.

	(1)	(2)	(3)	(4)	(5)	(6)
Panel A: h = 1-month						
MU	4.23					34.2
	(27.1)					(22.9)
RU		-8.89				-34.2**
		(12.9)				(16.8)
FU			9.01			10.5
			(11.2)			(7.04)
EPU				**-0.025**		**-0.029**
				(0.007)		(0.008)
GPR-USA					1.32**	1.21**
					(0.518)	(0.496)
Adj. R2	0.01	0.04	0.09	0.08	0.10	0.52
N.Obs.	289	289	289	289	289	289
Panel B: h = 3-month						
MU	7.76					37.9*
	(33.1)					(19.4)
RU		-9.15				**-43.1**
		(23.2)				(16.2)
FU			13.2			14.5
			(16.0)			(9.38)
EPU				**-0.0228**		**-0.026**
				(0.007)		(0.008)
GPR-USA					1.32**	**1.18**
					(0.608)	(0.439)
Adj. R2	0.02	0.03	0.12	0.07	0.10	0.57
N.Obs.	287	287	287	287	287	287
Panel C: h = 12-month						
MU	26.7					62.5**
	(54.3)					(30.1)
RU		-14.2				-80.9**
		(57.6)				(38.1)
FU			50.4			53.0**
			(51.9)			(24.9)
EPU				-0.022**		**-0.029**
				(0.009)		(0.009)
GPR-USA					0.655	0.624
					(0.995)	0.475
Adj. R2	0.07	0.01	0.23	0.06	0.02	0.59
N.Obs.	278	278	278	278	278	278

Note: This table reports regression results of U.S. probability of 5-year, 5-years-ahead inflation surpassing 3 percent (upper tail probability) on the following explanatory variables: Macroeconomic Uncertainty (MU), Real Economic Uncertainty (RU), and Financial Uncertainty (FU) measures of Jurado, Ludvigson, and Ng (2015), Economic Policy Uncertainty (EPU) of Baker, Bloom, and Davis (2016), and Geopolitical Risk (GPR) measure of Caldara and Iacoviello (2022). Standard errors in Panels A, B, and C are corrected for heteroskedasticity with lags $h = 1, 3, 12$, respectively, that are computed by following the Newey and West (1987a) methodology. */**/bolded coefficients indicate coefficients significant at the 10, 5, and 1 percent level, respectively. The sample period is from January 1999 to January 2023. The frequency is monthly.

Table 16: 5-Year Lower Tail Probability Regressions: U.S.

	(1)	(2)	(3)	(4)	(5)	(6)
Panel A: $h = 1$-month						
MU	2.93					-11.7**
	(7.36)					(5.74)
RU		7.08				**11.3**
		(4.75)				(4.10)
FU			0.437			-1.16
			(4.24)			(2.38)
EPU				**0.019**		**0.018**
				(0.002)		(0.003)
GPR-USA					-0.362	**-0.369**
					(0.309)	(0.14)
Adj. R2	0.02	0.17	0.00	0.31	0.04	0.50
N.Obs.	289	289	289	289	289	289
Panel B: $h = 3$-month						
MU	2.33					-11.4
	(5.77)					(7.42)
RU		7.84				12.3*
		(5.14)				(7.40)
FU			0.685			-1.07
			(6.95)			(3.69)
EPU				**0.018**		**0.017**
				(0.002)		(0.004)
GPR-USA					-0.335	-0.342**
					(0.275)	(0.145)
Adj. R2	0.01	0.14	0.00	0.27	0.04	0.44
N.Obs.	287	287	287	287	287	287
Panel C: $h = 12$-month						
MU	-3.6					-24.6
	(8.65)					(19.6)
RU		8.6				22.1
		(9.73)				(18.4)
FU			-2.85			-0.214
			(23.8)			(13.1)
EPU				0.012**		0.012**
				(0.005)		(0.005)
GPR-USA					-0.314	-0.334*
					(0.224)	(0.193)
Adj. R2	0.01	0.03	0.00	0.11	0.03	0.29
N.Obs.	278	278	278	278	278	278

Note: This table reports regression results of U.S. probability of 5-year average inflation declining below percent (lower tail probability) on the following explanatory variables: Macroeconomic Uncertainty (MU), Real Economic Uncertainty (RU), and Financial Uncertainty (FU) measures of Jurado, Ludvigson, and Ng (2015), Economic Policy Uncertainty (EPU) of Baker, Bloom, and Davis (2016), and Geopolitical Risk (GPR) measure of Caldara and Iacoviello (2022). Panels A, B, and C report regression results for $h = 1$, 3, 12 lags in independent variables. Standard errors in Panels A, B, and C are corrected for heteroskedasticity with lags $h = 1, 3, 12$, respectively, that are computed by following the Newey and West (1987a) methodology. */**/bolded coefficients indicate coefficients significant at the 10, 5, and 1 percent level, respectively. The sample period is from January 1999 to January 2023. The frequency is monthly.

Table 17: **5-Year 5-Years-Ahead Lower Tail Probability Regressions: U.S.**

	(1)	(2)	(3)	(4)	(5)	(6)
Panel A: $h = 1$-month						
MU	2.19					**-12.1**
	(5.82)					(3.54)
RU		6.02*				**12.5**
		(3.16)				(2.54)
FU			-0.027			-1.03
			(4.06)			(1.57)
EPU				**0.016**		**0.013**
				(0.002)		0.002
GPR-USA					-0.228	-0.194*
					(0.201)	(0.103)
Adj. R2	0.02	0.21	0.00	0.35	0.03	0.61
N.Obs.	289	289	289	289	289	289
Panel B: $h = 3$-month						
MU	1.51					**-13.0**
	(4.51)					(4.57)
RU		6.78**				**15.0**
		(3.44)				(4.65)
FU			-0.023			-0.947
			(6.22)			(2.36)
EPU				**0.015**		**0.011**
				(0.002)		(0.002)
GPR-USA					-0.216	-0.172*
					(0.171)	(0.103)
Adj. R2	0.01	0.18	0.00	0.31	0.02	0.57
N.Obs.	287	287	287	287	287	287
Panel C: $h = 12$-month						
MU	-2.69					-28.2**
	(6.07)					(12.9)
RU		10.6				**31.6**
		(7.11)				(11.2)
FU			-2.75			0.566
			(23.3)			(8.71)
EPU				**0.011**		0.008**
				(0.003)		(0.004)
GPR-USA					-0.245	-0.204*
					(0.163)	(0.117)
Adj. R2	0.01	0.08	0.00	0.18	0.03	0.49
N.Obs.	278	278	278	278	278	278

Note: This table reports regression results of U.S. probability of 5-year 5-years-ahead inflation declining below 1 percent (lower tail probability) on the following explanatory variables: Macroeconomic Uncertainty (MU), Real Economic Uncertainty (RU), and Financial Uncertainty (FU) measures of Jurado, Ludvigson, and Ng (2015), Economic Policy Uncertainty (EPU) of Baker, Bloom, and Davis (2016), and Geopolitical Risk measure (GPR) of Caldara and Iacoviello (2022). Panels A, B, and C report regression results for $h = 1$, 3, 12 lags in independent variables. Standard errors in Panels A, B, and C are corrected for heteroskedasticity with lags $h = 1, 3, 12$, respectively, that are computed by following the Newey and West (1987a) methodology. */**/bolded coefficients indicate coefficients significant at the 10, 5, and 1 percent level, respectively. The sample period is from January 1999 to January 2023. The frequency is monthly.

Table 18: Upper Tail Probabilities Regressions: Euro Area

	5-year			4-to-5-years		
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A: $h = 1$-month						
E-EPU	**0.020**		**0.020**	0.008*		0.008*
	(0.004)		(0.004)	(0.004)		(0.005)
EA GPR		3.29	-0.057		1.31	-0.066
		(3.04)	(1.89)		(1.64)	(1.59)
Adj. R2	0.46	0.05	0.46	0.19	0.02	0.19
N.Obs.	289	289	289	289	289	289
Panel B: $h = 3$-month						
E-EPU	**0.020**		**0.020**	0.008		0.008*
	(0.004)		(0.004)	(0.004)		(0.004)
EA GPR		3.64	0.431		1.48	0.187
		(3.68)	(2.78)		(2.16)	(1.82)
Adj. R2	0.44	0.07	0.44	0.18	0.03	0.17
N.Obs.	287	287	287	287	287	287
Panel C: $h = 12$-month						
E-EPU	**0.016**		**0.018**	0.005		0.006
	(0.005)		(0.006)	(0.006)		(0.008)
EA GPR		-0.635	-2.86		-0.963	-1.75
		(6.88)	(1.74)		(3.40)	(1.33)
Adj. R2	0.24	0.00	0.27	0.07	0.01	0.09
N.Obs.	278	278	278	278	278	278

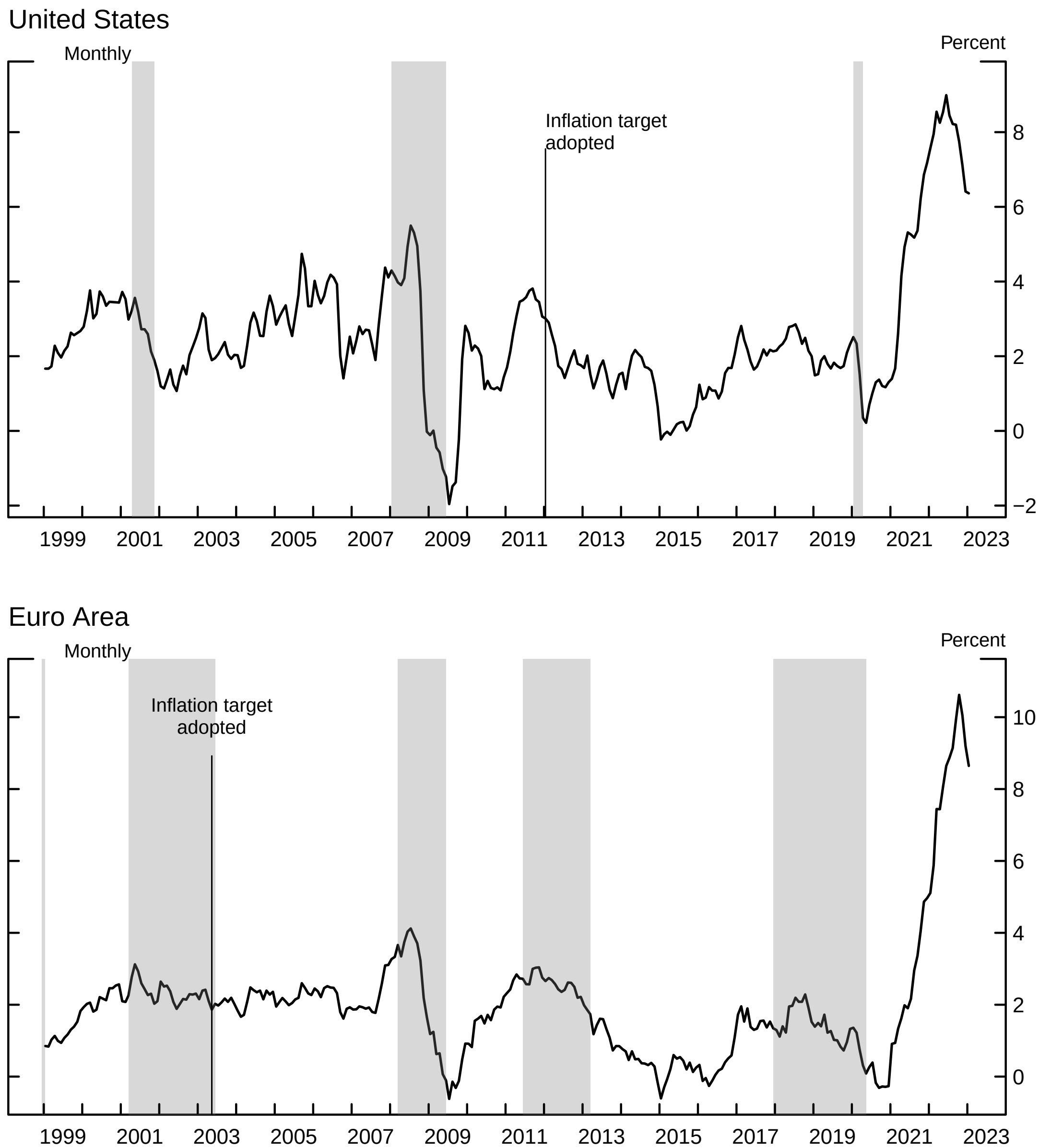
Note: This table reports regression results of euro-area probability of 5- and 4-to-5-year average inflation surpassing 3 percent (upper tail probability) on the following explanatory variables: European Economic Policy Uncertainty (EPU) of Baker, Bloom, and Davis (2016) and euro-area Geopolitical Risk (GPR) constructed using GDP-weighted country-specific GPR indexes of Caldara and Iacoviello (2022). Panels A, B, and C report regression results for $h = 1, 3, 12$ lags in independent variables. Standard errors in Panels A, B, and C are corrected for heteroskedasticity with lags $h = 1, 3, 12$, respectively, that are computed by following the Newey and West (1987a) methodology. */bolded coefficients indicate coefficients significant at the 10 and 1 percent level, respectively. The sample period is from January 1999 to January 2023. The frequency is monthly.

Table 19: Lower Tail Probabilities Regressions, Euro Area

	5-year			4-to-5-years		
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A: $h = 1$-month						
E-EPU	**0.025**		**0.027**	0.011**		0.012**
	(0.006)		0.005	(0.005)		(0.005)
EA GPR		1.90	-2.63*		0.784	-1.20
		(2.05)	(1.49)		(1.30)	1.32
Adj. R2	0.4	0.01	0.42	0.23	0.003	0.24
N.Obs.	289	289	289	289	289	289
Panel B: $h = 3$-month						
E-EPU	**0.026**		**0.028**	0.011**		0.012**
	(0.006)		(0.006)	(0.005)		(0.005)
EA GPR		1.94	-2.57		0.847	-1.13
		(1.68)	(1.37)		(1.14)	(1.14)
Adj. R2	0.40	0.01	0.42	0.23	0.00	0.24
N.Obs.	287	287	287	287	287	287
Panel C: $h = 12$-month						
E-EPU	**0.029**		**0.030**	0.013**		0.013**
	(0.007)		(0.007)	(0.006)		(0.006)
EA GPR		1.94	-1.77		1.06	-0.618
		(2.76)	(2.08)		(1.14)	(1.15)
Adj. R2	0.41	0.004	0.41	0.26	0.00	0.26
N.Obs.	278	278	278	278	278	278

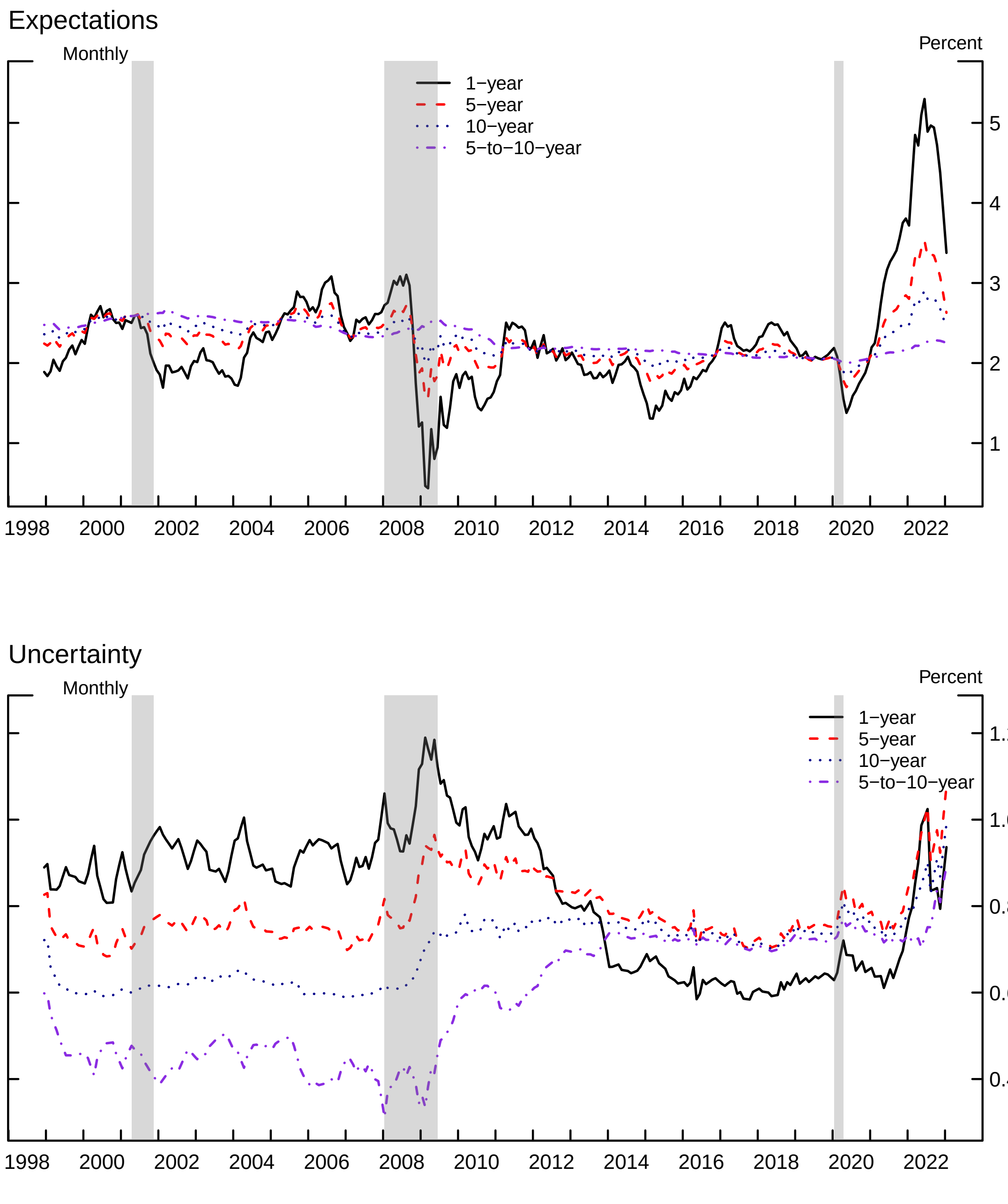
Note: This table reports regression results of euro-area probability of 5- and 4-to-5-year average inflation declining below 1 percent (lower tail probability) on the following explanatory variables: European Economic Policy Uncertainty (EPU) of Baker, Bloom, and Davis (2016) and euro-area Geopolitical Risk (GPR) constructed using GDP-weighted country-specific GPR indexes of Caldara and Iacoviello (2022). Panels A, B, and C report regression results for $h = 1, 3, 12$ lags in independent variables. Standard errors in Panels A, B, and C are corrected for heteroskedasticity with lags $h = 1, 3, 12$, respectively, that are computed by following the Newey and West (1987a) methodology.*/**/bolded coefficients indicate coefficients significant at the 10, 5, and 1 percent level, respectively. The sample period is from January 1999 to January 2023. The frequency is monthly.

Figure 1: Realized Inflation in the U.S. and Euro Area



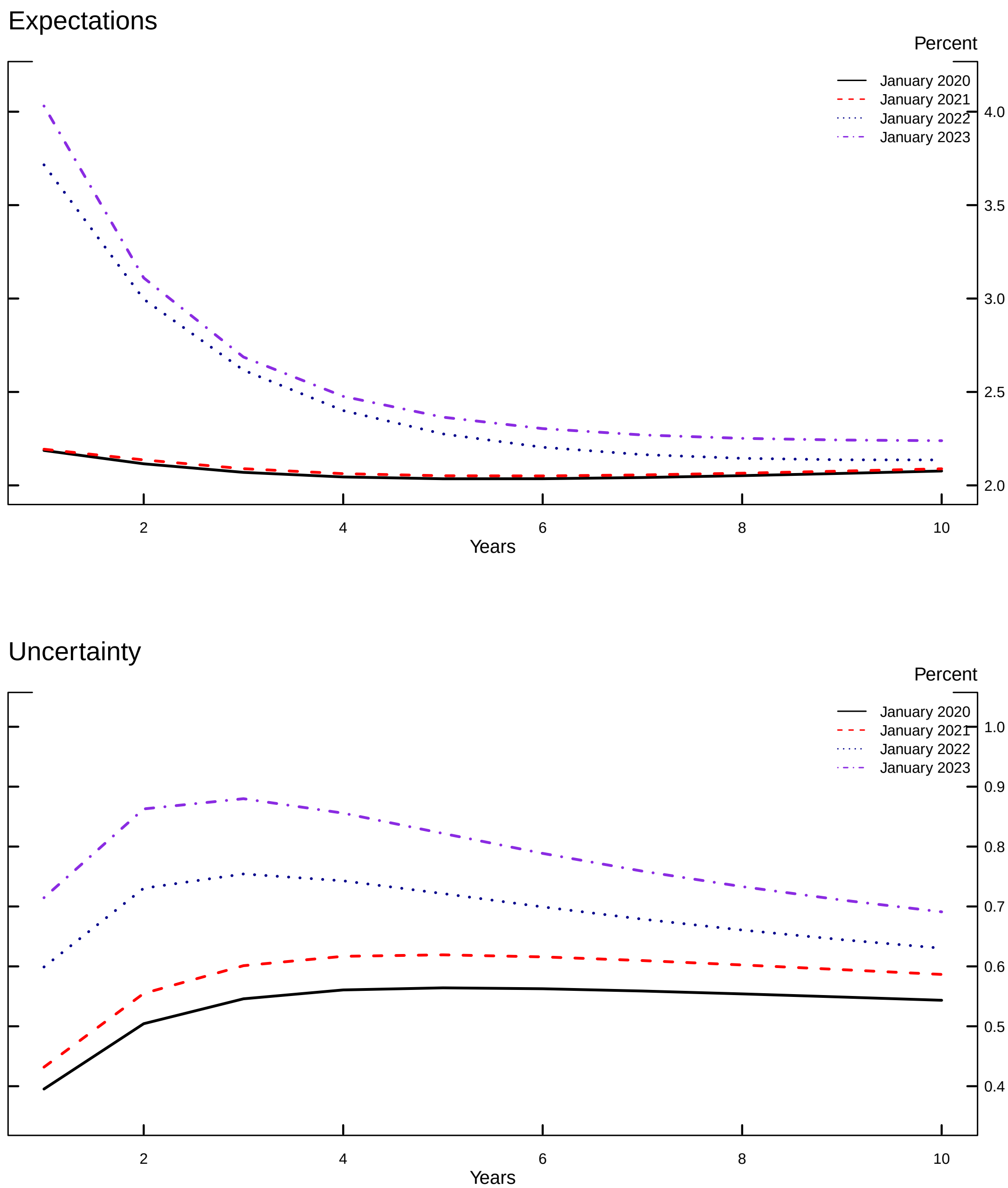
Note: This figure shows time series of realized Consumer Price Index (CPI) inflation in the United States (top panel) and realized Harmonized Index of Consumer Prices (HICP) inflation in the euro area (bottom panel). The sample period is from January 1999 to January 2023. The frequency is monthly. Shaded areas represent the National Bureau of Economic Research (NBER) and the Organisation for Economic Co-operation and Development (OECD) recessions for top and bottom panels, respectively. Source: Federal Reserve Economic Data; Statistical Office of the European Communities.

Figure 2: Inflation Expectations and Uncertainty in the U.S.



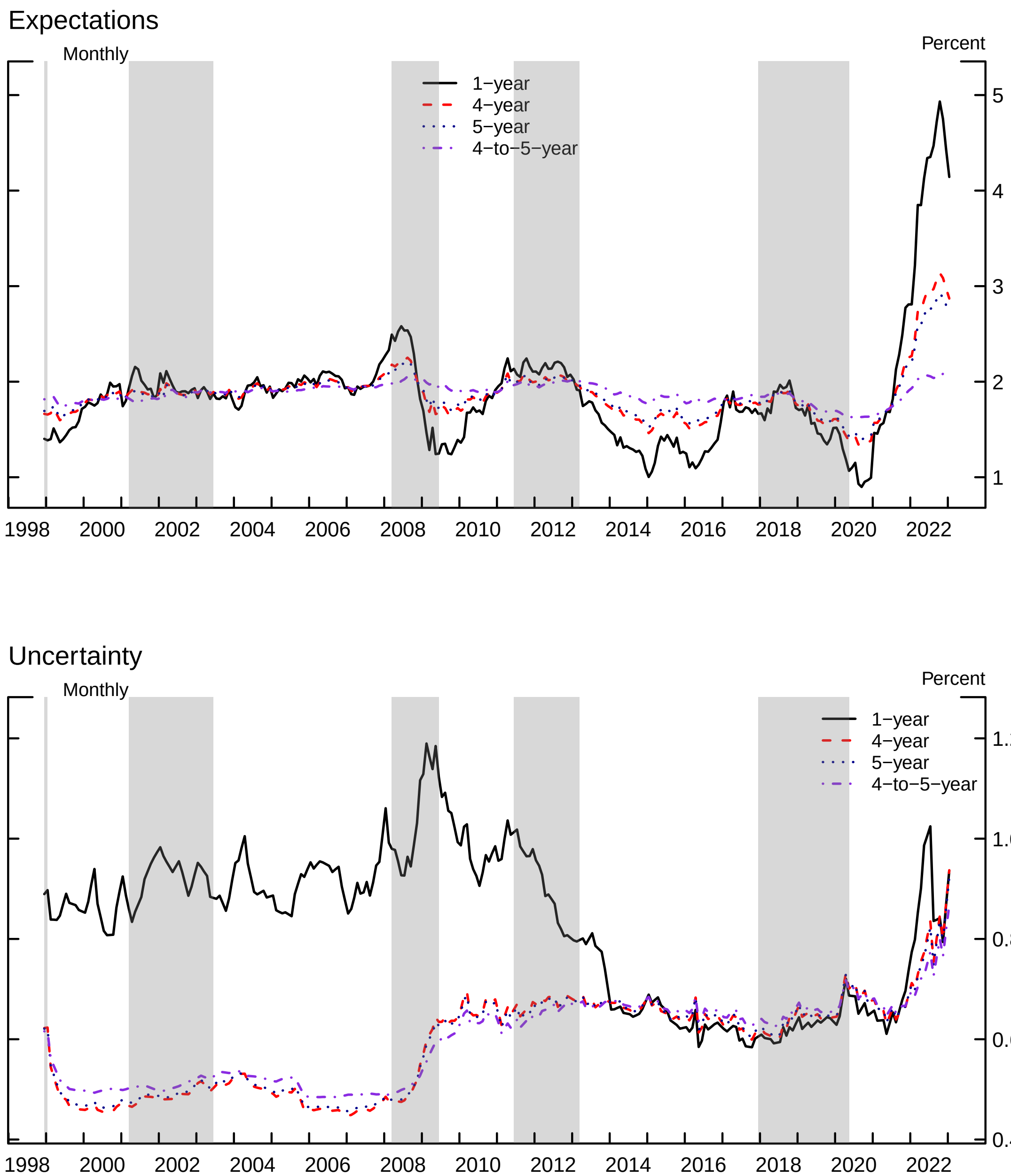
Note: The top and bottom panels show a time series of U.S. inflation expectations and uncertainty, respectively, implied by the Grishchenko, Mouabbi, and Renne (2019) state-space survey-based model for one-, five-, ten-, and five-to-ten-year ahead horizons. The sample period is from December 1998 to January 2023. The frequency is monthly. Shaded areas represent the National Bureau of Economic Research (NBER) recessions.

Figure 3: Term Structure of U.S. Inflation Expectations and Uncertainty



Note: This figure shows term structures of expected inflation and inflation uncertainty in the U.S. implied by the Grishchenko, Mouabbi, and Renne (2019) state-space survey-based model in January 2020, January 2021, January 2022, and January 2023. Panels A and B indicate the term structures of forward one-year inflation expectations and uncertainty, respectively. Uncertainty is defined as a square root of the estimated second moments of the fitted inflation distribution.

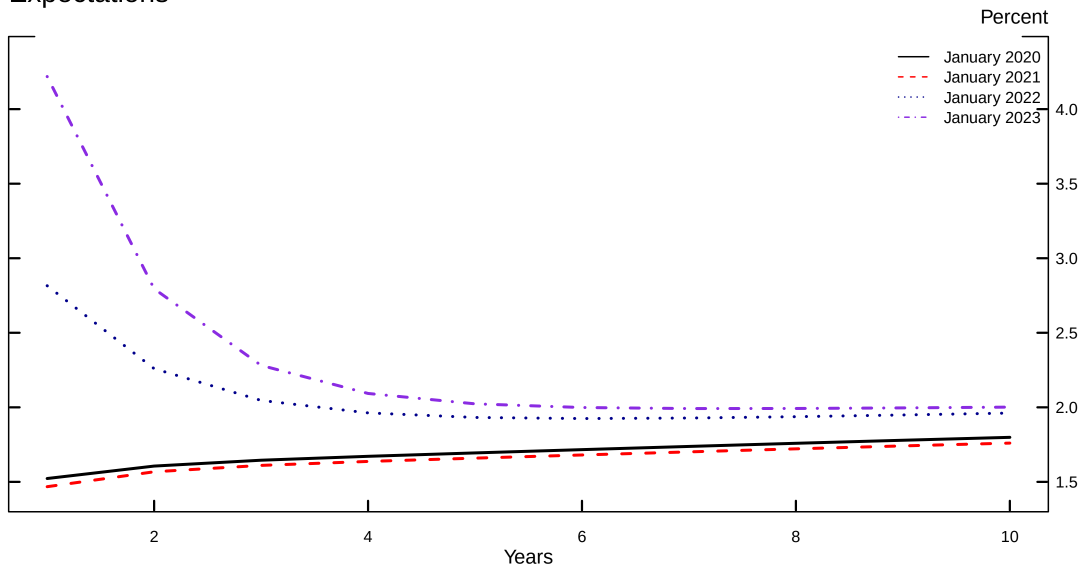
Figure 4: Inflation Expectations and Uncertainty in the Euro Area



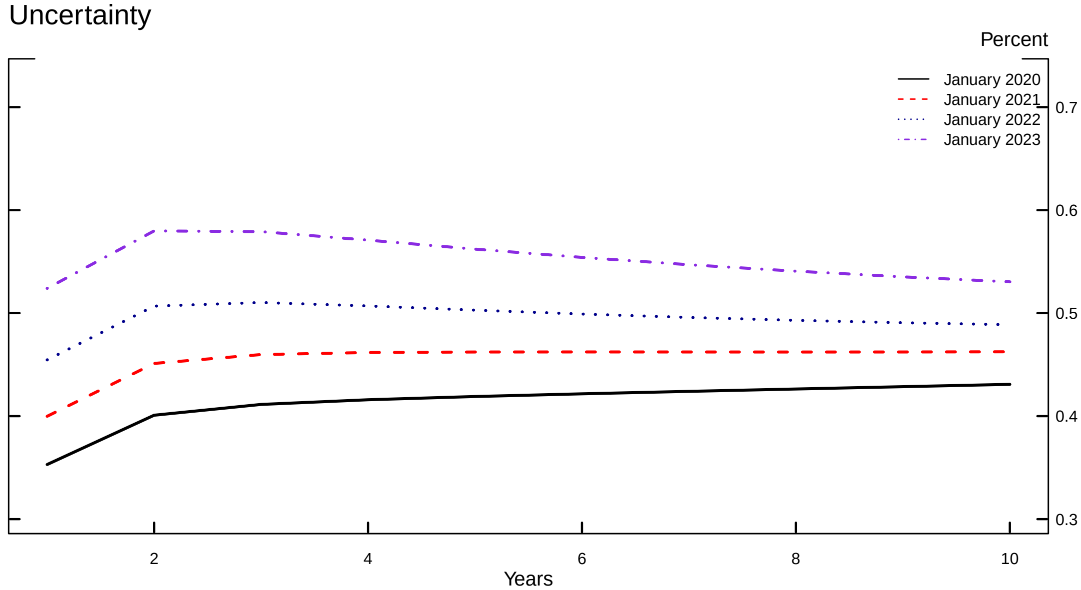
Note: The top and bottom panels show a time series of euro-area inflation expectations, respectively, implied by the Grishchenko, Mouabbi, and Renne (2019) state-space survey-based model for one-, four-, five-, and four-to-five-year ahead horizons. The sample period is from December 1998 to January 2023. The frequency is monthly. Shaded areas represent the Organisation for Economic Co-operation and Development (OECD) recessions.

Figure 5: Term Structure of Euro-Area Inflation Expectations and Uncertainty

Expectations

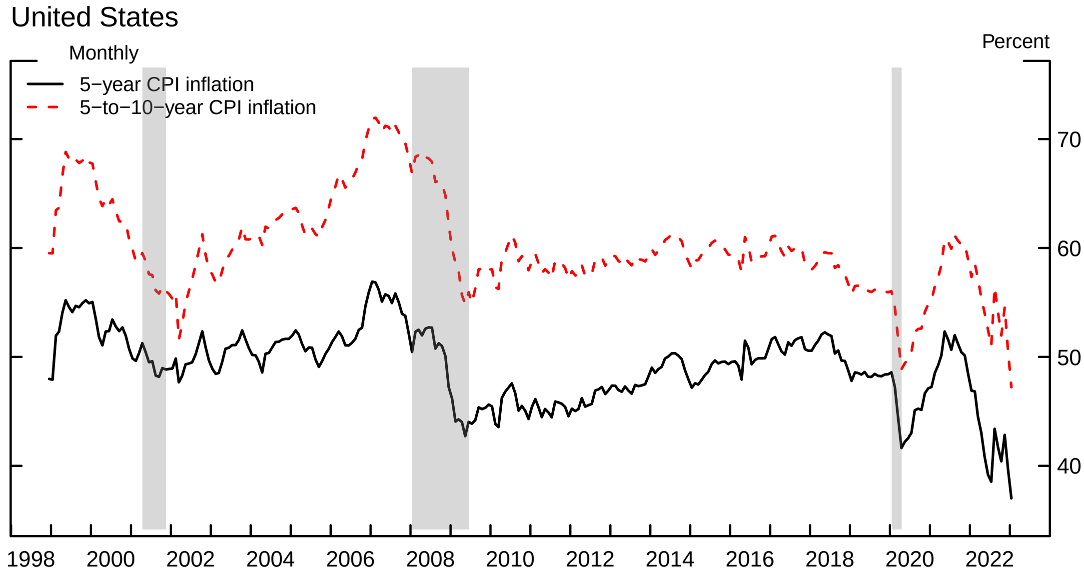


Uncertainty



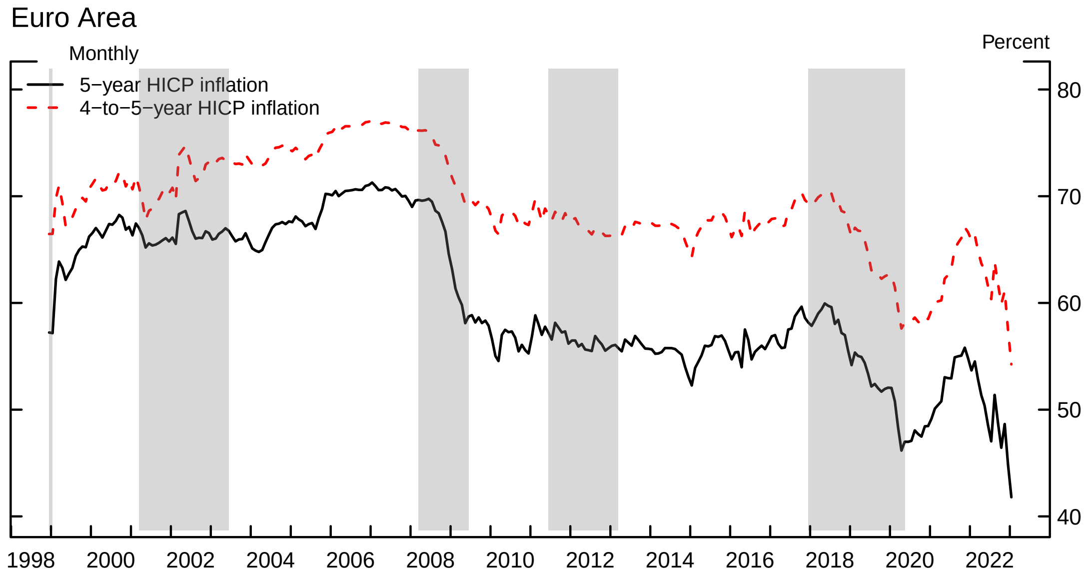
Note: This figure shows term structures of expected inflation and inflation uncertainty in the euro area implied by the Grishchenko, Mouabbi, and Renne (2019) state-space survey-based model in January 2020, January 2021, January 2022, and January 2023. Panels A and B indicate the term structures of forward one-year inflation expectations and uncertainty, respectively. Uncertainty is defined as a square root of the estimated second moments of the fitted inflation distribution.

Figure 6: U.S. Inflation Anchoring Probabilities



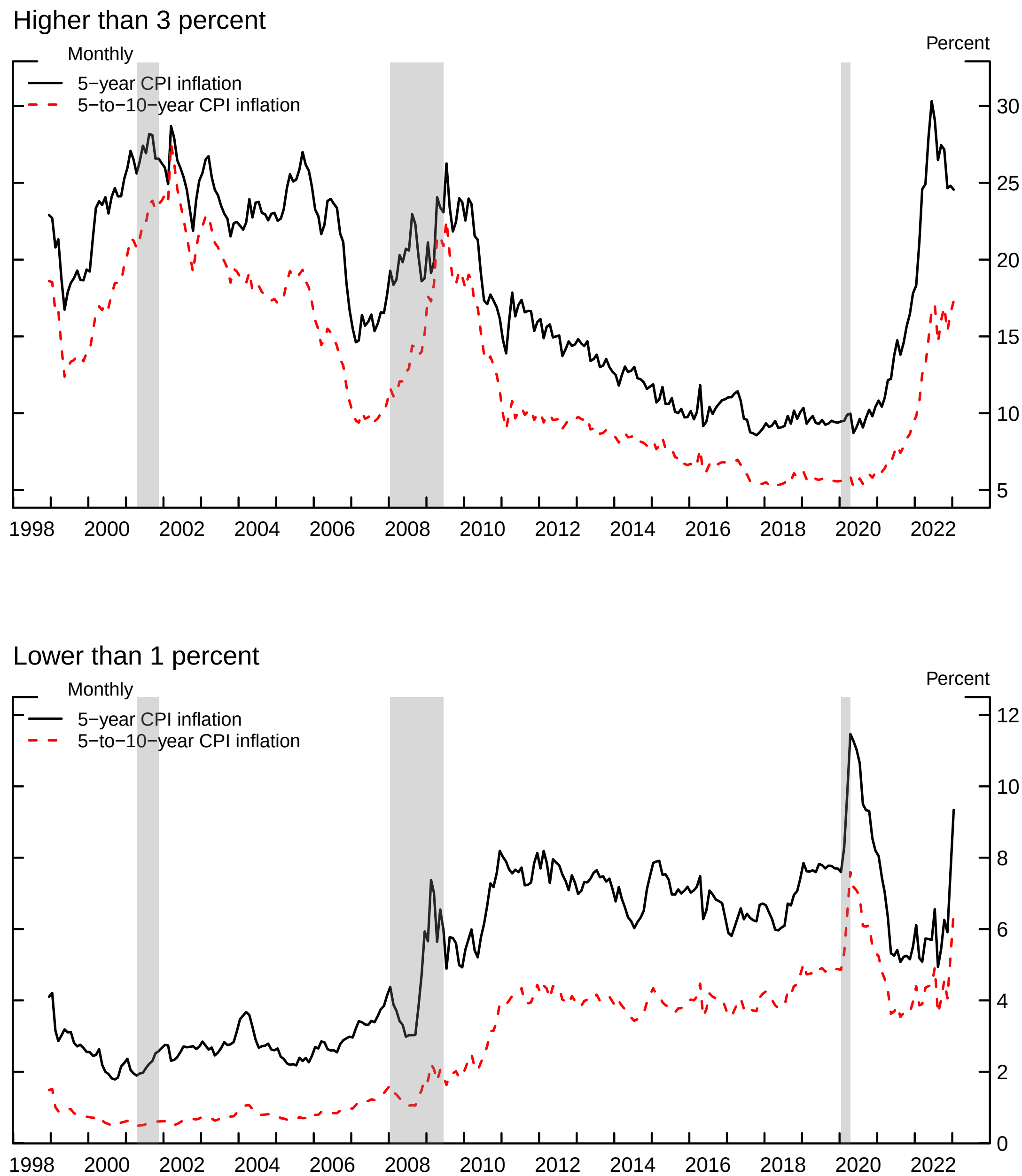
Note: This figure shows a time series of probabilities of future average U.S. Consumer Price Index (CPI) inflation over the next five years (solid black line) and over the five-to-ten-year ahead horizon (dashed red line) being in the range of 1.8 to 2.8 percent. Probabilities are implied by the estimates of the Grishchenko, Mouabbi, and Renne (2019) state-space survey-based model. The sample period is from December 1998 to January 2023. The frequency is monthly. Shaded areas represent the National Bureau of Economic Research (NBER) recessions.

Figure 7: Euro-Area Inflation Anchoring Probabilities



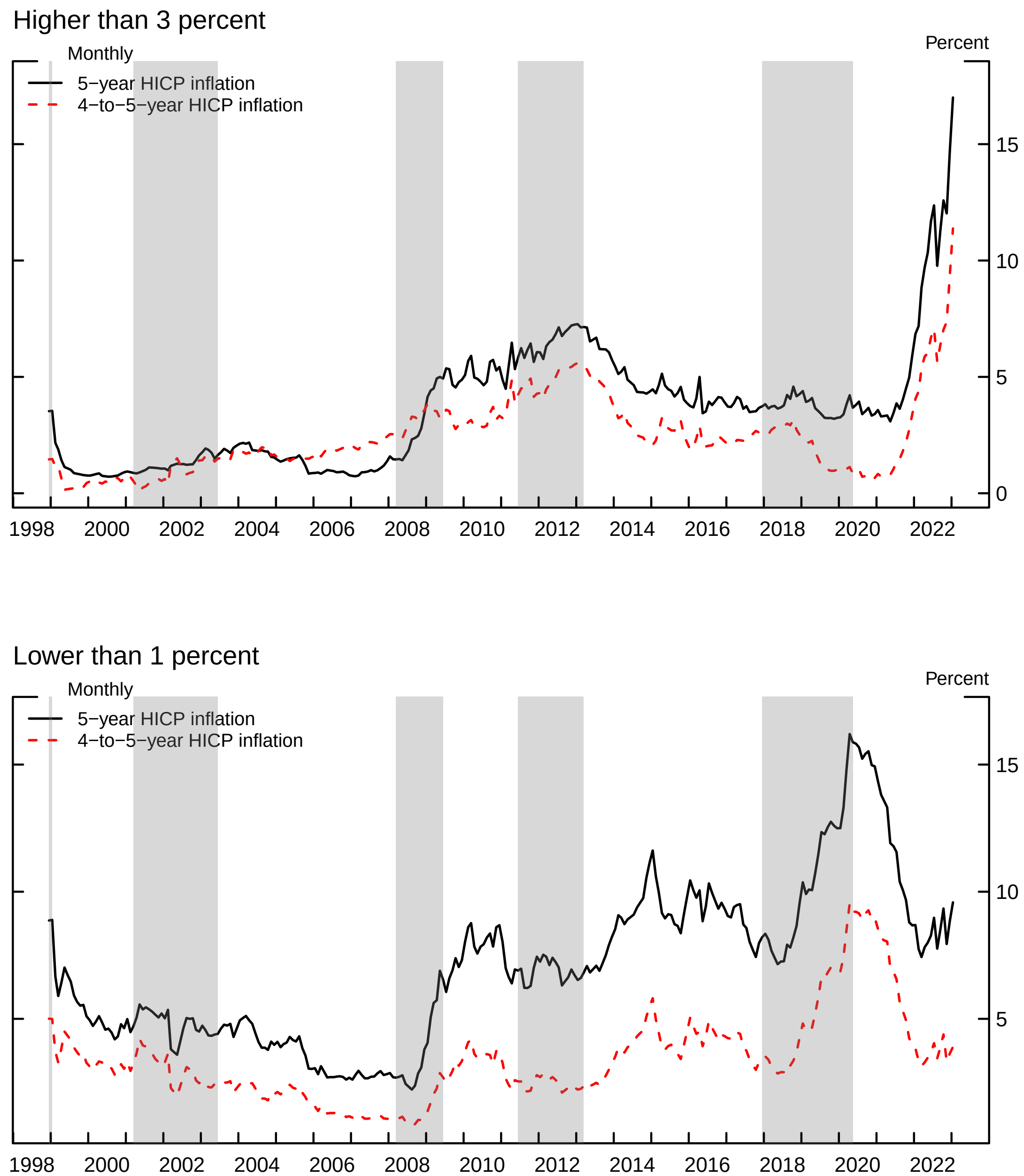
Note: This figure shows a time series of probabilities of future average euro-area Harmonized Index of Consumer Prices (HICP) inflation over the next five years (solid black line) and over the four-to-five-year ahead horizon (dashed red line) being in the range of 1.5 to 2.5 percent. Probabilities are implied by the estimates of the Grishchenko, Mouabbi, and Renne (2019) state-space survey-based model. The sample period is from December 1998 to January 2023. The frequency is monthly. Shaded areas represent the Organisation for Economic Co-operation and Development (OECD) recessions.

Figure 8: U.S. Inflation Tail Probabilities



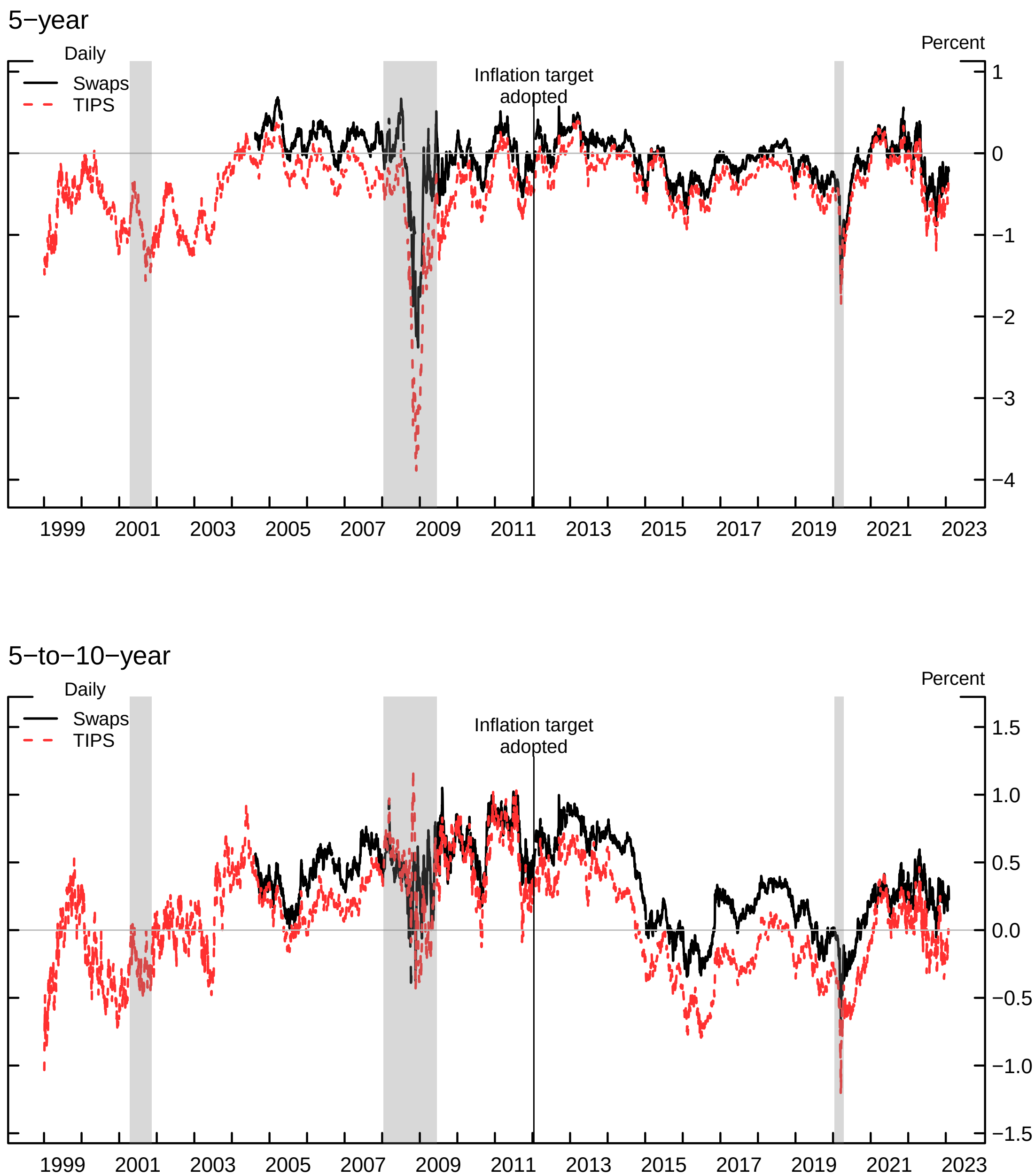
Note: This figure shows time series of probabilities of future average U.S. Consumer Price Index (CPI) inflation over the next five years (solid black line) and over the five-to-ten-year ahead horizon (dashed red line) being higher than 3 percent (top panel) and lower than 1 percent (bottom panel). Probabilities are implied by the estimates of the Grishchenko, Mouabbi, and Renne (2019) state-space survey-based model. The sample period is from December 1998 to January 2023. The frequency is monthly. Shaded areas represent the National Bureau of Economic Research (NBER) recessions.

Figure 9: Euro-Area Inflation Tail Probabilities



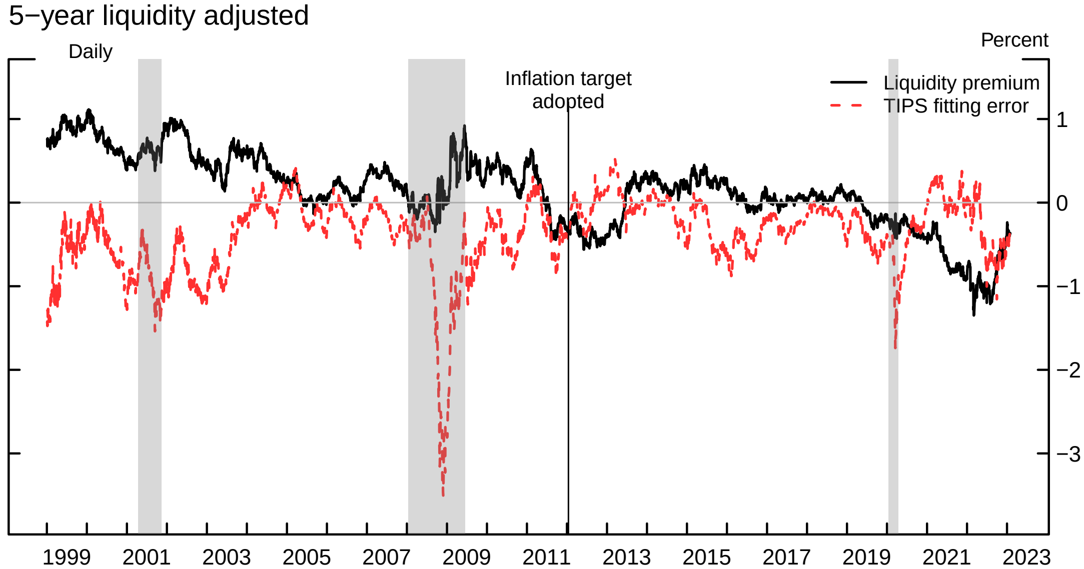
Note: This figure shows time series of probabilities of future average euro-area Harmonized Index of Consumer Prices (HICP) inflation over the next five years (solid black line) and over the four-to-five-year ahead horizon (dashed red line) being higher than 3 percent (top panel) and lower than 1 percent (bottom panel). Probabilities are implied by the estimates of the Grishchenko, Mouabbi, and Renne (2019) state-space survey-based model. The sample period is from December 1998 to January 2023. The frequency is monthly. Shaded areas represent the Organisation for Economic Co-operation and Development (OECD) recessions.

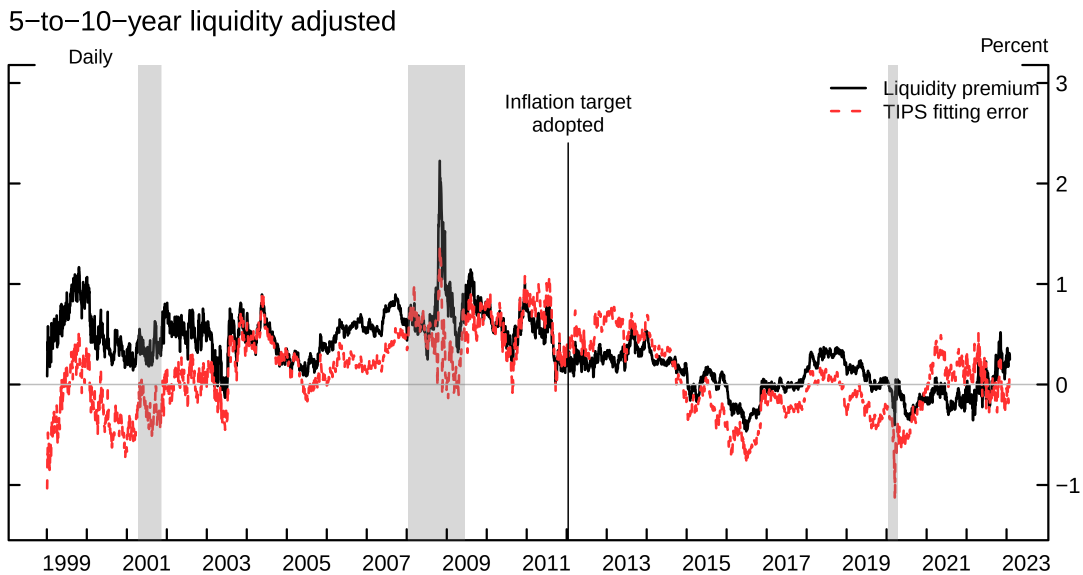
Figure 10: U.S. Inflation Risk Premium



Note: This figure shows time series of U.S. inflation risk premiums defined as the difference between either TIPS-based inflation compensation (dashed red line) or inflation swap-based inflation compensation (solid black line) and inflation expectations implied by the Grishchenko, Mouabbi, and Renne (2019) state-space survey-based model. Inflation risk premiums are shown for five- and five-to-ten-year ahead horizons. The sample period is from January 4, 1999, to January 31, 2023 for TIPS-based inflation risk premiums and from August 16, 2004, to January 31, 2023 for swap-based inflation risk premiums. The frequency is daily. Shaded areas represent the National Bureau of Economic Research (NBER) recessions. Source: Board of Governors of the Federal Reserve System, Yield Curve Models and Data; Bloomberg Per Security Data; authors' calculations.

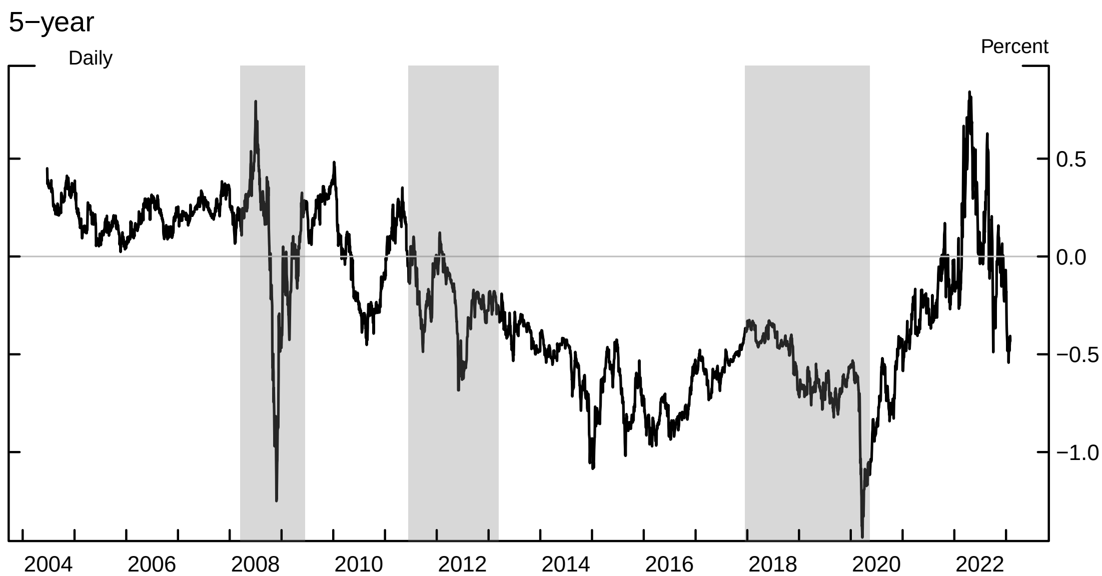
Figure 11: U.S. Liquidity-Adjusted TIPS-based Inflation Risk Premium

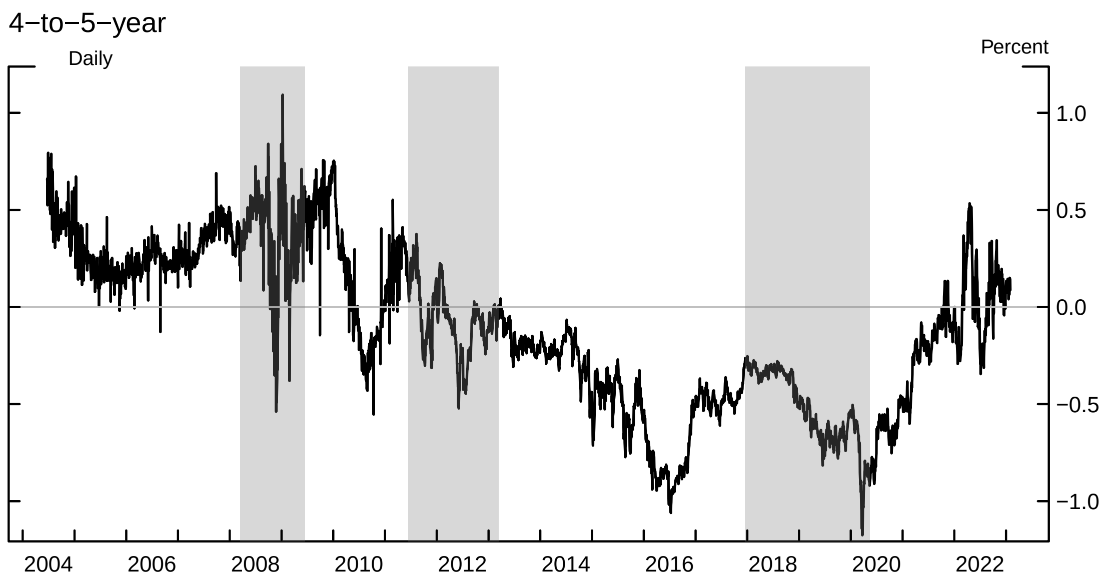




Note: This figure shows a time series of Treasury Inflation-Protected Securities (TIPS)-based inflation risk premiums in the U.S. that are adjusted for liquidity. The premiums are defined as the difference between TIPS-based inflation compensation adjusted for liquidity and inflation expectations implied by the state-space survey-based model in Grishchenko, Mouabbi, and Renne (2019). Liquidity adjustment uses either the D'Amico, Kim, and Wei (2018) model (*liquidity premium*, solid black line), or the TIPS fitting error computed by following Hu, Pan, and Wang (2013) methodology (*TIPS fitting error*, dashed red line). Liquidity-adjusted inflation risk premiums are shown for five- and five-to-ten-year ahead horizons. The sample period is from January 4, 1999, to January 31, 2023. The frequency is daily. Shaded areas represent the National Bureau of Economic Research (NBER) recessions. Source: Board of Governors of the Federal Reserve System, Yield Curve Models and Data; Bloomberg Per Security Data; authors' calculations.

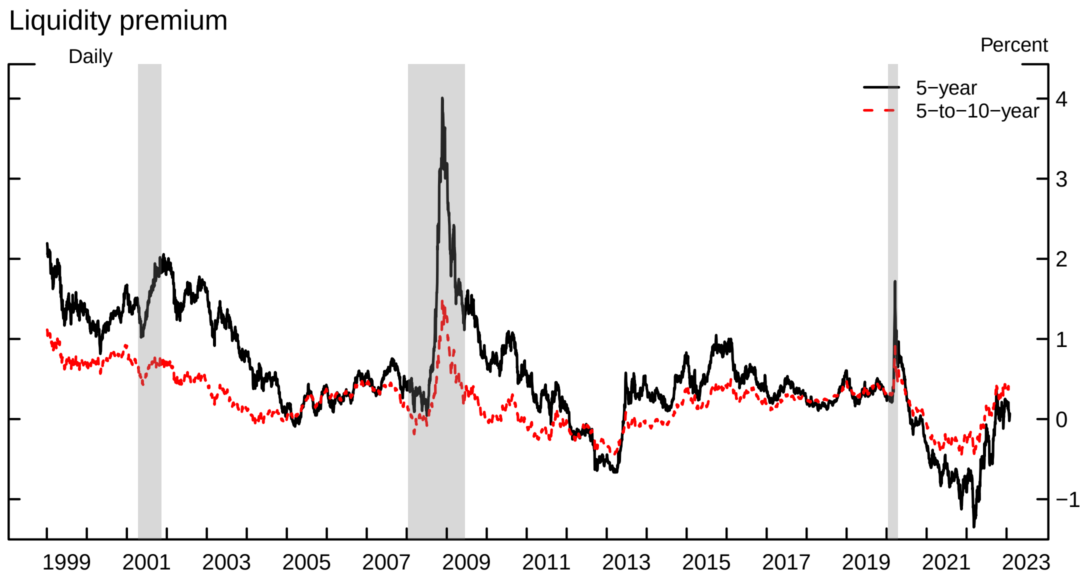
Figure 12: Euro-Area Inflation Risk Premium

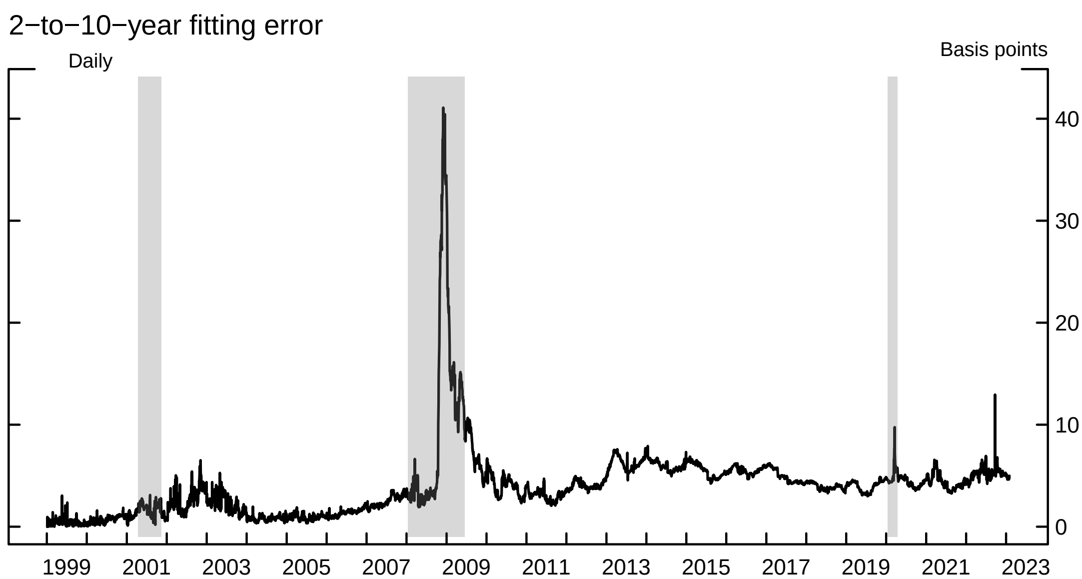




Note: This figure shows time series of inflation risk premiums in the euro area defined as the difference between comparable-maturity euro-area inflation swap rates and inflation expectations in the Euro Area implied by the Grishchenko, Mouabbi, and Renne (2019) state-space survey-based model. Inflation risk premiums are shown for five- and four-to-five-year ahead horizons. The sample period is from June 22, 2004, to January 31, 2023. Frequency is daily. Shaded areas represent the Organisation for Economic Co-operation and Development (OECD) recessions. Source: Bloomberg Per Security Data; authors' calculations.

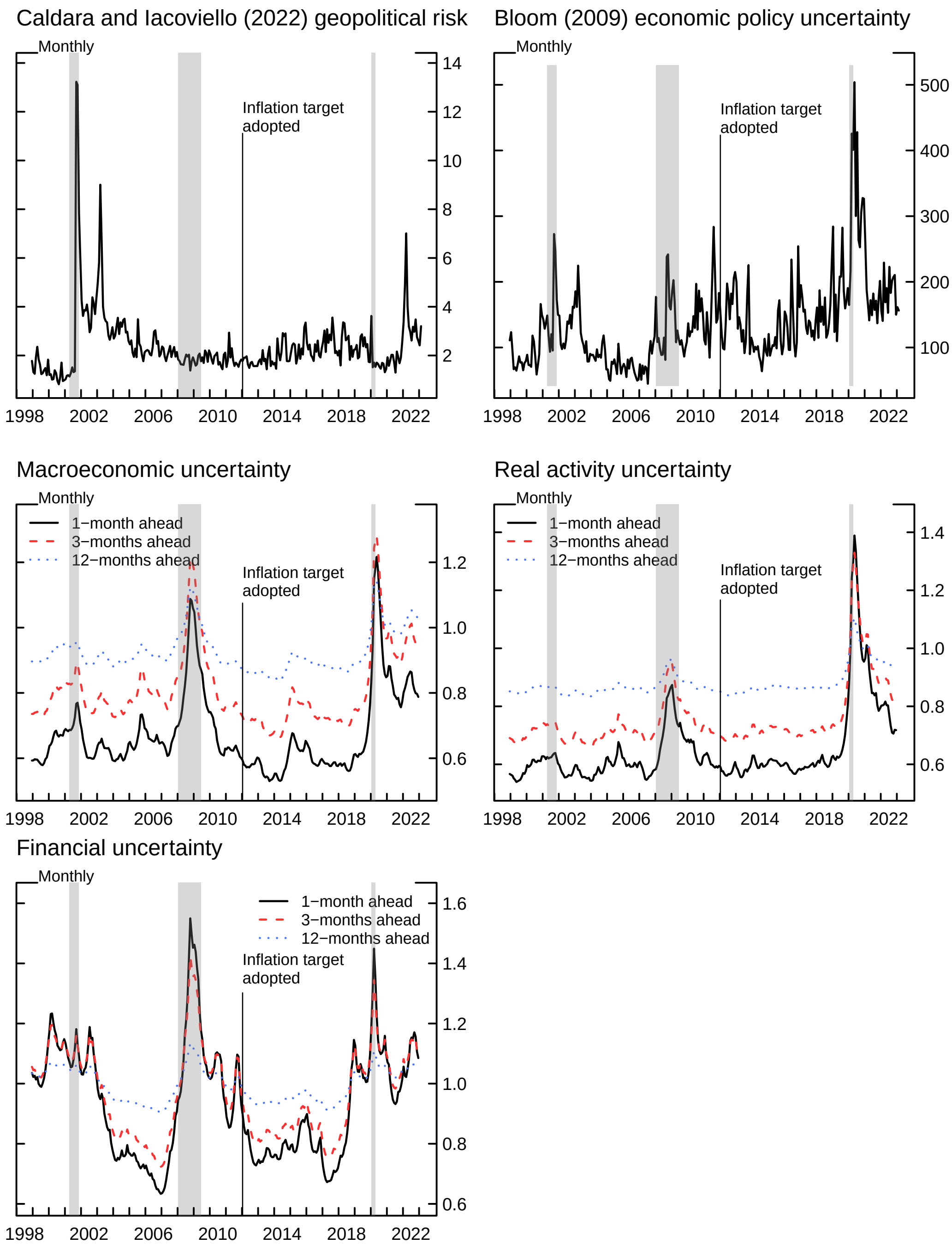
Figure 13: U.S. Liquidity Premium and Fitting Error





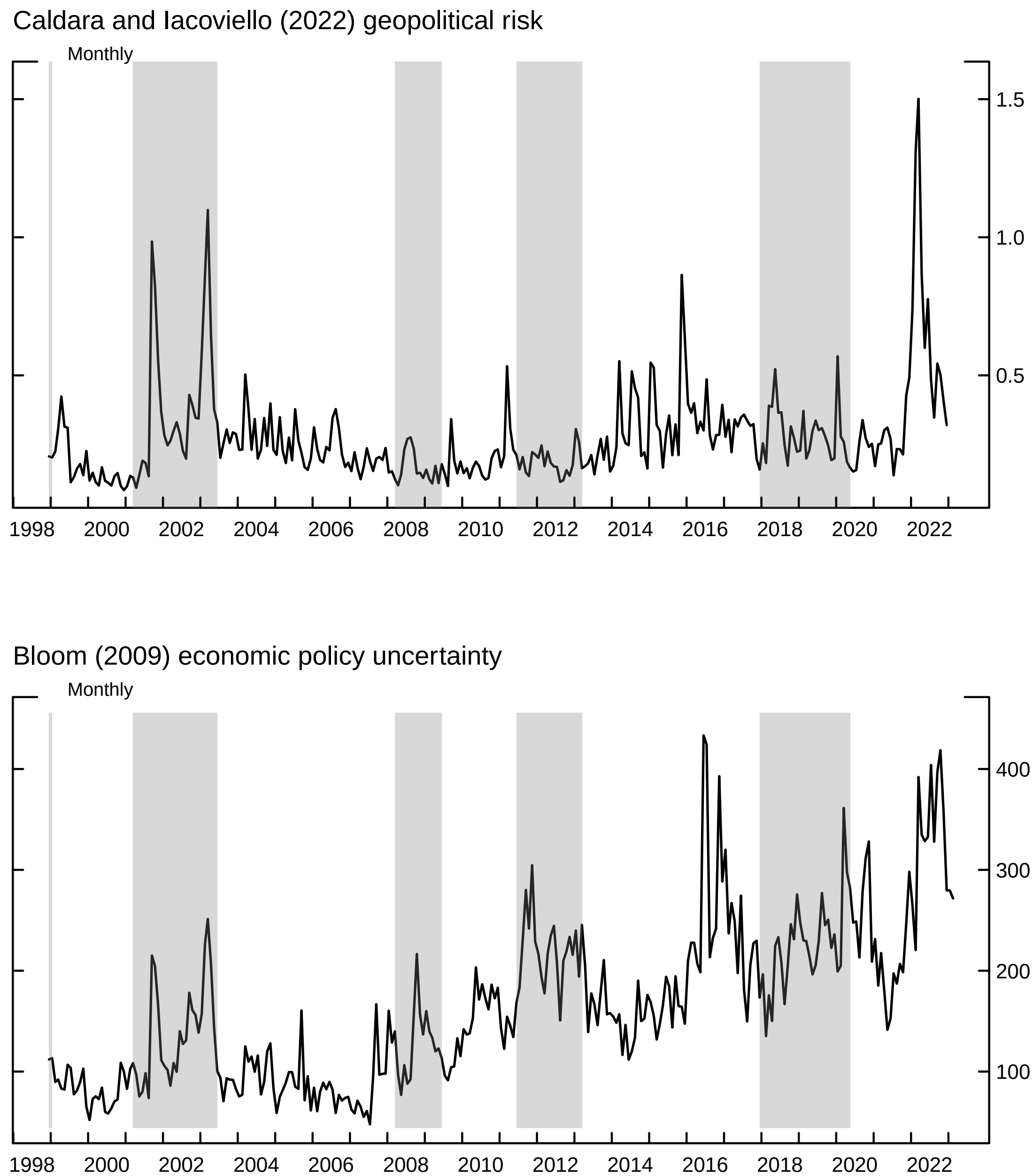
Note: This figure shows a time series of the liquidity premiums (top panel) from the D'Amico, Kim, and Wei (2018) model and the TIPS fitting error (bottom panel) computed by following Hu, Pan, and Wang (2013) methodology. Liquidity premiums are shown for five- and five-to-ten-year ahead horizons. Fitting error is the average absolute fit error for TIPS yield curve for securities with remaining maturity between two and ten years. The sample period is from January 4, 1999 to January 31, 2023. The frequency is daily. Shaded areas represent the National Bureau of Economic Research (NBER) recessions. Source: Board staff calculations.

Figure 14: U.S. Uncertainty Measures



Note: The top left panel shows the geopolitical risk seris (GPR) of Caldara and Iacoviello (2022); the top right panel shows the economic policy uncertainty series (EPU) of Baker, Bloom, and Davis (2016); the middle left, middle right, and bottom left series show macroeconomic uncertainty, real economic activity uncertainty, and financial uncertainty series of Jurado, Ludvigson, and Ng (2015). The sample period is from January 1999 to January 2023. The frequency is monthly. Shaded areas represent the National Bureau of Economic Research (NBER) recessions. Source: `https://www.sydneyludvigson.com/macro-and-financial-uncertainty-indexes` and `https://www.policyuncertainty.com/us_monthly.html` and `https://www.matteoiacoviello.com/gpr_country.htm`.

Figure 15: Euro-Area Uncertainty Measures



Note: The top panel shows the time series of the euro-area geopolitical risk measure of Caldara and Iacoviello (2022); the bottom panel shows the time series of the European economic policy uncertainty (EEPU) of Baker, Bloom, and Davis (2016). The sample period is from January 1999 to January 2023. The frequency is monthly. Shaded areas represent the Organisation for Economic Co-operation and Development (OECD) recessions. Source: `https://www.policyuncertainty.com/europe_monthly.html` and `https://www.matteoiacoviello.com/gpr_country.htm`

A Predictive regressions: Robustness checks

Table A.1: Expected Inflation Predictive Regressions, U.S.

	5-year			5-to-10-years		
Panel A: h=1						
Upper Tail Probability	**0.031**		0.021	**0.032**		**0.019**
	(0.011)		(0.028)	(0.001)		(0.001)
Lower Tail Probability		**-0.080**	-0.038		**-0.103**	**-0.052**
		(0.012)	(0.062)		(0.014)	(0.005)
Adj. R2	0.35	0.32	0.38	0.91	0.87	0.99
N.Obs.	289	289	289	289	289	289
Panel B: h=3						
Upper Tail Probability	0.028**		0.016	**0.032**		**0.019**
	(0.011)		(0.028)	(0.002)		(0.002)
Lower Tail Probability		**-0.075**	-0.043		**-0.102**	**-0.053**
		(0.014)	(0.058)		(0.015)	(0.009)
Adj. R2	0.28	0.28	0.32	0.89	0.86	0.97
N.Obs.	287	287	287	287	287	287
Panel C: h=12						
Upper Tail Probability	0.013		-0.007	**0.028**		0.011
	(0.016)		(0.016)	(0.005)		(0.007)
Lower Tail Probability		-0.049	-0.064*		**-0.099**	-0.068*
		(0.049)	(0.035)		(0.023)	(0.037)
Adj. R2	0.06	0.12	0.12	0.73	0.80	0.84
N.Obs.	278	278	278	278	278	278

Note: This table reports regression results of US five-year and five-to-10-year inflation expectations on US inflation tail probabilities. *Upper Tail* represents probability of inflation being higher than 3 percent; *Lower tail* represents probability of inflation being lower than 1 percent. Panels A, B, and C report regression results for $h = 1, 3, 12$ leads in the dependent variable. Standard errors in Panels A, B, and C are corrected for heteroskedasticity with lags $h = 1, 3, 12$, respectively, that are computed by following the Newey and West (1987a) methodology. */**/bolded coefficients indicate coefficients significant at the 10, 5, and 1 percent level, respectively. The sample period is from January 1999 to January 2023. The frequency is monthly.

Table A.2: Expected Inflation Predictive Regressions, Euro Area

	5-year			4-to-5-years		
Panel A: h=1						
Upper Tail Probability	0.041		0.075	**0.046**		**0.034**
	(0.941)		(0.054)	(0.012)		(0.004)
Lower Tail Probability		-0.033	**-0.059**		**-0.045**	**-0.036**
		(0.029)	(0.017)		(0.003)	(0.003)
Adj. R2	0.16	0.18	0.64	0.51	0.65	0.91
N.Obs.	289	289	289	289	289	289
Panel B: h=3						
Upper Tail Probability	0.035		0.070	**0.045**		0.032*
	(29.7)		(0.197)	(0.015)		(0.019)
Lower Tail Probability		-0.031	-0.054		**-0.042**	**-0.035**
		(0.033)	(0.051)		(0.009)	(0.010)
Adj. R2	0.10	0.16	0.49	0.43	0.58	0.79
N.Obs.	287	287	287	287	287	287
Panel C: h=12						
Upper Tail Probability	-0.014		-0.010	0.020		0.009
	(0.077)		(0.118)	(0.258)		(0.093)
Lower Tail Probability		-0.008	-0.005		-0.025	-0.023
		(0.051)	(0.054)		(0.074)	(0.056)
Adj. R2	0.01	0.01	0.01	0.07	0.21	0.22
N.Obs.	278	278	278	278	278	278

Note: This table reports regression results of euro-area five- and four-to-five-year inflation expectations on Euro Area inflation tail probabilities. *Upper Tail* represents probability of inflation being higher than 3 percent; *Lower tail* represents probability of inflation being lower than 1 percent. Panels A, B, and C report regression results for $h = 1, 3, 12$ leads in the dependent variable. Standard errors in Panels A, B, and C are corrected for heteroskedasticity with lags $h = 1, 3, 12$, respectively, that are computed by following the Newey and West (1987a) methodology. */**/bolded coefficients indicate coefficients significant at the 10, 5, and 1 percent level, respectively. The sample period is from January 1999 to January 2023. The frequency is monthly.

Table A.3: Inflation Uncertainty Predictive Regressions, U.S.

	5-year			5-to-10-years		
Panel A: h=1						
Upper Tail Probability	0.002		**0.013**	-0.017		0.000
	(0.013)		(0.001)	(0.608)		(0.006)
Lower Tail Probability		0.013	**0.041**		**0.071**	**0.072**
		(0.017)	(0.005)		(0.011)	(0.023)
Adj. R2	0.03	0.18	0.76	0.51	0.81	0.80
N.Obs.	289	289	289	289	289	289
Panel B: h=3						
Upper Tail Probability	0.002		**0.013**	-0.017		0.001
	(0.022)		(0.003)	(0.087)		(0.025)
Lower Tail Probability		0.012	**0.038**		**0.072**	0.076
		(0.013)	(0.009)		(0.019)	(0.090)
Adj. R2	0.02	0.14	0.62	0.50	0.82	0.82
N.Obs.	287	287	287	287	287	287
Panel C: h=12						
Upper Tail Probability	0.000		0.007*	-0.018*		0.002
	(0.007)		(0.004)	(0.009)		(0.006)
Lower Tail Probability		0.007	0.021*		**0.073**	0.078**
		(0.009)	(0.013)		(0.021)	(0.036)
Adj. R2	0.00	0.05	0.15	0.54	0.83	0.83
N.Obs.	278	278	278	278	278	278

Note: This table reports regression results of US five-year and five-to-10-year inflation uncertainty on US inflation tail probabilities. *Upper Tail* represents probability of inflation being higher than 3 percent; *Lower tail* represents probability of inflation being lower than 1 percent. Panels A, B, and C report regression results for $h = 1, 3, 12$ leads in the dependent variable. Standard errors in Panels A, B, and C are corrected for heteroskedasticity with lags $h = 1, 3, 12$, respectively, that are computed by following the Newey and West (1987a) methodology. */**/bolded coefficients indicate coefficients significant at the 10, 5, and 1 percent level, respectively. The sample period is from January 1999 to January 2023. The frequency is monthly.

Table A.4: Inflation Uncertainty Predictive Regressions, Euro Area

	5-year			4-to-5-years		
Panel A: h=1						
Upper Tail Probability	**0.036**		**0.028**	0.032*		**0.043**
	(0.002)		(0.001)	(0.017)		(0.001)
Lower Tail Probability		0.023	**0.013**		0.025**	**0.036**
		(0.025)	(0.000)		(0.012)	(0.003)
Adj. R2	0.83	0.55	0.97	0.36	0.31	0.92
N.Obs.	289	289	289	289	289	289
Panel B: h=3						
Upper Tail Probability	**0.038**		**0.031**	0.034		**0.046**
	(0.004)		(0.002)	(0.089)		(0.003)
Lower Tail Probability		0.022	**0.012**		0.025*	**0.036**
		(0.242)	(0.002)		(0.013)	(0.006)
Adj. R2	0.83	0.52	0.94	0.36	0.29	0.91
N.Obs.	287	287	287	287	287	287
Panel C: h=12						
Upper Tail Probability	0.040		0.032	0.033		0.049
	(0.050)		(0.059)	(0.043)		(0.670)
Lower Tail Probability		0.020	0.010		0.022	0.034
		(0.033)	(0.030)		(0.267)	(0.264)
Adj. R2	0.66	0.44	0.74	0.28	0.24	0.80
N.Obs.	278	278	278	278	278	278

Note: This table reports regression results of Euro Area five- and four-to-five-year inflation uncertainty on Euro Area inflation tail probabilities. *Upper Tail* represents the probability of inflation being higher than 3 percent; *Lower tail* represents the probability of inflation being lower than 1 percent. Panels A, B, and C report regression results for $h = 1, 3, 12$ leads in the dependent variable. Standard errors in Panels A, B, and C are corrected for heteroskedasticity with lags $h = 1, 3, 12$, respectively, that are computed by following the Newey and West (1987a) methodology. */**/bolded coefficients indicate coefficients significant at the 10, 5, and 1 percent level, respectively. The sample period is from January 1999 to January 2023. The frequency is monthly.

Table A.5: Inflation Risk Premium Predictive Regressions, U.S.

	5-year			5-to-10-years		
Panel A: Swap-based inflation risk premiums						
Upper Tail Probability	0.003		-0.004	0.023*		0.021*
	(0.013)		(0.010)	(0.012)		(0.011)
Lower Tail Probability		-0.021	-0.029		-0.054	-0.009
		(0.053)	(0.054)		(0.033)	(0.041)
Adj. R2	0.00	0.01	0.01	0.12	0.08	0.12
N.Obs.	220	220	220	220	220	220
Panel B: TIPS-based inflation risk premiums						
Upper Tail Probability	-0.025*		**-0.024**	0.011		0.007
	(0.015)		(0.009)	(0.013)		(0.015)
Lower Tail Probability		0.052	0.002		-0.035	-0.016
		(0.056)	(0.053)		(0.044)	(0.055)
Adj. R2	0.09	0.05	0.09	0.03	0.02	0.02
N.Obs.	287	287	287	287	287	287
Panel C: AKW-liquidity-adjusted inflation risk premiums						
Upper Tail Probability	0.027		-0.007	**0.030**		0.001
	(0.024)		(0.033)	(0.007)		(0.011)
Lower Tail Probability		**-0.102**	-0.116		**-0.122**	**-0.120**
		(0.032)	(0.084)		(0.020)	(0.036)
Adj. R2	0.13	0.27	0.27	0.26	0.39	0.39
N.Obs.	287	287	287	287	287	287
Panel D: HPW-liquidity-adjusted inflation risk premiums						
Upper Tail Probability	-0.026*		**-0.024**	0.010		0.007
	(0.014)		(0.009)	(0.014)		(0.015)
Lower Tail Probability		0.057	0.008		-0.030	-0.012
		(0.054)	(0.051)		(0.045)	(0.057)
Adj. R2	0.11	0.07	0.10	0.02	0.02	0.02
N.Obs.	287	287	287	287	287	287

Note: This table reports regression results for the U.S. five- and five-to-ten-year inflation risk premium on US inflation tail probabilities. *Upper Tail* represents the probability of inflation being higher than 3 percent; *Lower tail* represents the probability of inflation being lower than 1 percent. Panels A, B, C, and D report regression results for $h = 3$ leads in the dependent variable. Standard errors across all panels are corrected for heteroskedasticity with three lags, that are computed by following the Newey and West (1987a) methodology. */**/bolded coefficients indicate coefficients significant at the 10, 5, and 1 percent level, respectively. The sample period is from January 1999 to January 2023. The frequency is monthly.

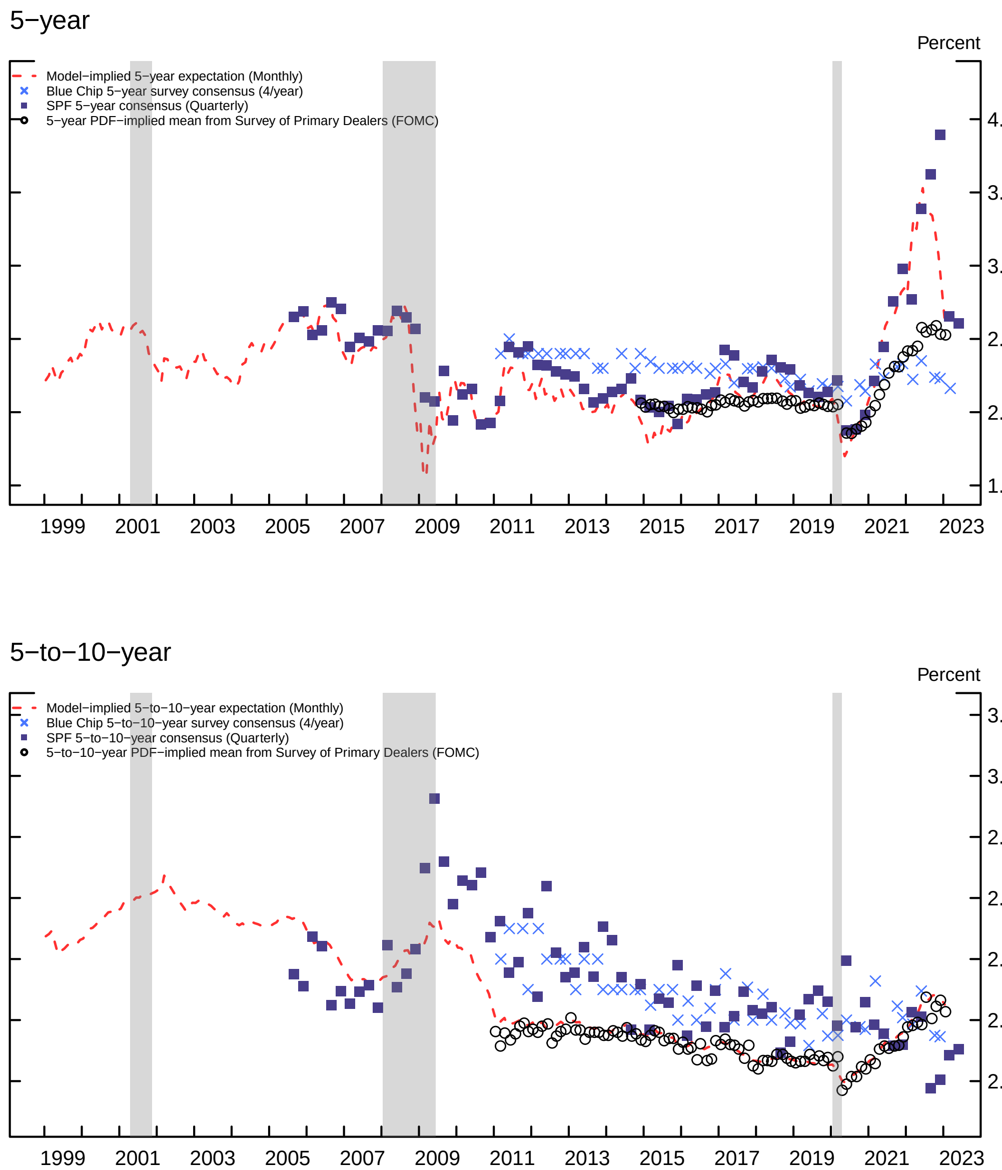
Table A.6: Inflation Risk Premium Predictive Regressions, Euro Area

	5-year			4-to-5-years		
Upper Tail Probability	-0.023		0.019	0.051		-0.012
	(0.041)		(0.024)	(0.058)		(0.099)
Lower Tail Probability		**-0.089**	**-0.094**		**-0.140**	**-0.143**
		(0.016)	(0.022)		(0.030)	(0.030)
Adj. R2	0.02	0.49	0.50	0.03	0.47	0.46
N.Obs.	224	224	224	224	224	224

Note: This table reports regression results for the euro-area five- and four-to-five-year inflation risk premium on euro-area inflation-tail probabilities. *Upper Tail* represents the probability of inflation being higher than 3 percent; *Lower tail* represents the probability of inflation being lower than 1 percent. Regression results are reported for $h = 3$ leads in the dependent variable. Standard errors are corrected for heteroskedasticity with three lags, that are computed by following the Newey and West (1987a) methodology. */**/bolded coefficients indicate coefficients significant at the 10, 5, and 1 percent level, respectively. The sample period is from January 1999 to January 2023. The frequency is monthly.

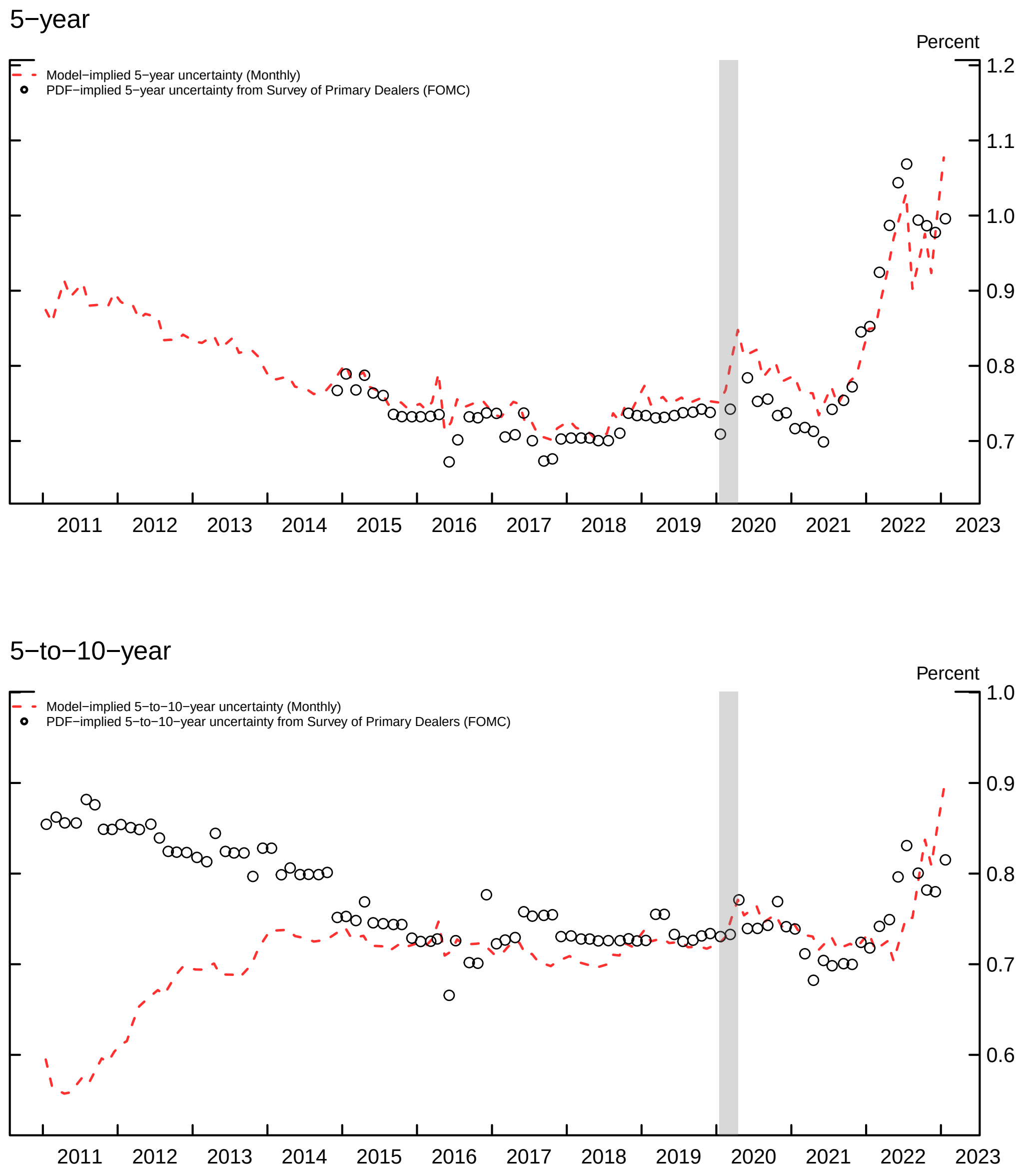
B Model Fit of Survey-Based Data

Figure B.1: Survey-Based and Model-Implied Measures of U.S. Inflation Expectations



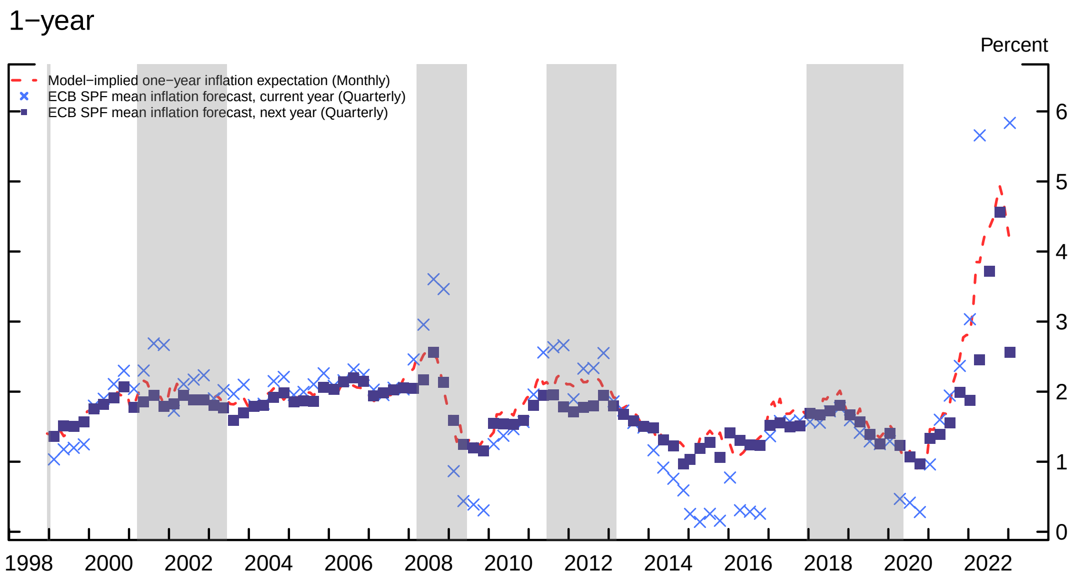
Note: This figure shows the measure of U.S. inflation expectations, estimated by the Grishchenko, Mouabbi, and Renne (2019) state-space survey-based model at the monthly frequency, in dashed red, at the 5- and 5-to-10-year horizons, in the top and bottom panels, respectively. The panels show consensus inflation forecasts of Blue Chip Survey of Financial Forecasts and the Blue Chip Survey of Economic Indicators (Blue Chip survey, available 4 times a year, shown in blue x's), the Survey of Professional Forecasters (SPF, available at the quarterly frequency, shown in purple squares), and the Survey of Primary Dealers (SPD, available at the FOMC frequency, shown in black circles) for 5- and 5-to-10-year horizons. U.S. model-implied inflation expectations are shown at the monthly frequency. The sample period for the Blue Chip surveys is from March 2011 to January 2023. The sample period for the SPF is from August 2005 to January 2023. The sample period for the SPD is from January 2011 (top panel) or December 2014 (bottom panel) to January 2023. The sample period for the model-implied measures of inflation expectations is from January 1999 to January 2023. Shaded areas represent the National Bureau of Economic Research (NBER) recessions.

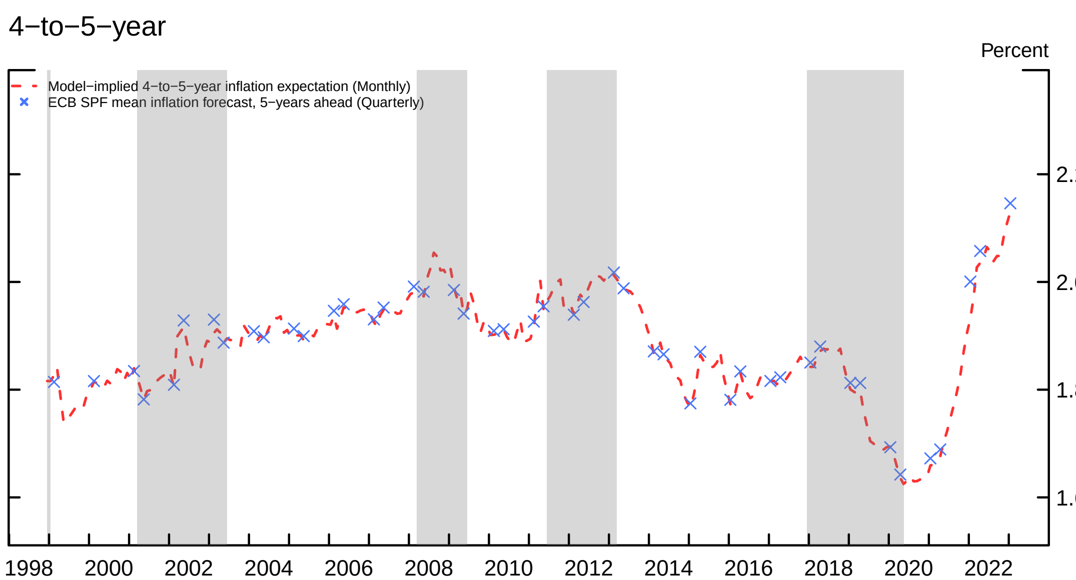
Figure B.2: Survey-Based and Model-Implied Measures of U.S. Inflation Uncertainty



Note: This figure shows the measure of U.S. inflation uncertainty, estimated by the Grishchenko, Mouabbi, and Renne (2019) state-space survey-based model at the monthly frequency, in dashed red line, at the 5- and 5-to-10-year horizons, in the left and right panels, respectively. The panels show inflation uncertainty implied by the probability distributions of the Survey of Primary Dealers (SPD), at the FOMC frequency, in the black circles, at respective horizons. The sample period for the model-implied measures of inflation uncertainty is from January 2011 to January 2023. The sample period for the 5- and 5-to-10-year SPD inflation uncertainty measure is from December 2014 to January 2023 and from January 2011 to January 2023, respectively. Shaded areas represent the National Bureau of Economic Research (NBER) recessions.

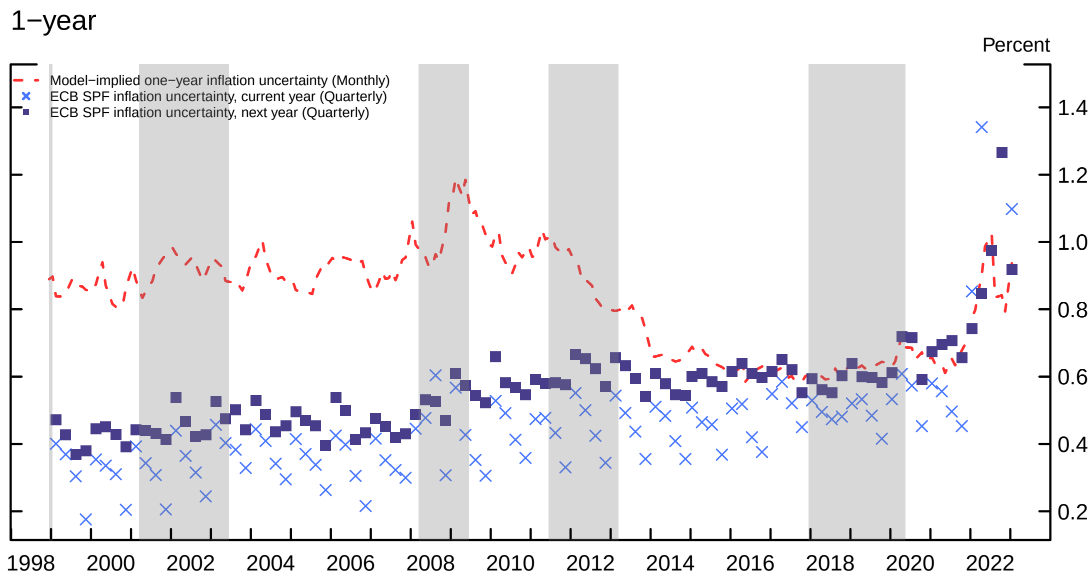
Figure B.3: Survey-Based and Model-Implied Measures of Euro-area Inflation Expectations

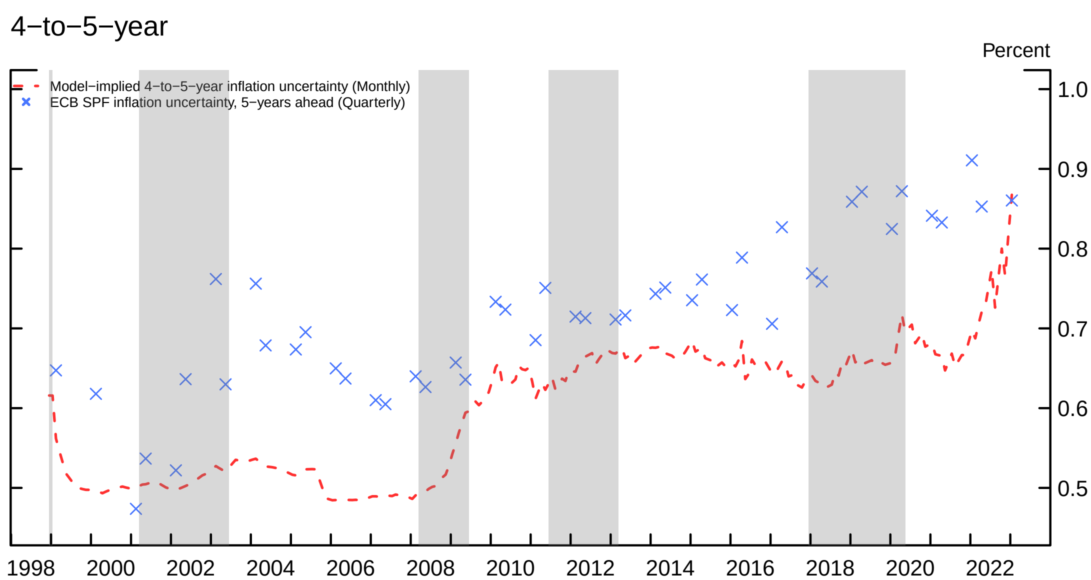




Note: This figure shows the measures of euro-area inflation expectations, estimated by the Grishchenko, Mouabbi, and Renne (2019) state-space survey-based model at the monthly frequency compared with the European Central Bank Survey of Professional Forecasters (ECB SPF) data. The top panel shows the 1-year estimated expected inflation in the dashed red line, the ECB SPF pdf-implied mean inflation forecast for the current and the next year, at the quarterly frequency, shown in the blue x's and in the purple squares, respectively. The bottom panel shows the 4-to-5-year estimated expected inflation in the dashed red line and the 5-year ahead ECB SPF pdf-implied mean inflation forecast, at the quarterly frequency, shown in the blue x's. The sample period is from January 1999 to January 2023. Shaded areas represent the Organisation for Economic Co-operation and Development (OECD) recessions.

Figure B.4: Survey-Based and Model-Implied Measures of Euro-area Inflation Uncertainty





Note: This figure shows the measure of euro-area inflation uncertainty, estimated by the Grishchenko, Mouabbi, and Renne (2019) state-space survey-based model at the monthly frequency compared with the European Central Bank Survey of Professional Forecasters (ECB SPF) data. The top panel shows the 1-year estimated inflation uncertainty in the dashed red line, the ECB SPF pdf-implied mean inflation uncertainty for the current and the next year, at the quarterly frequency, shown in the blue x's and in the purple squares, respectively. The bottom panel shows the 4-to-5-year estimated inflation uncertainty in the dashed red line and the 5-year ahead ECB SPF pdf-implied mean inflation uncertainty, at the quarterly frequency, shown in the blue x's. The sample period is from January 1999 to January 2023. Shaded areas represent the Organisation for Economic Co-operation and Development (OECD) recessions.