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Forecasting inflation: A comparison of the ECB's short-term inflation projections and inflation-linked swaps

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Abstract

According to the efficient-market hypothesis, forecasts derived from efficient market prices should be unbeatable. However, numerous institutions, including the European Central Bank, regularly publish forecasts for future inflation that deviate from market expectations. We investigate the relative predictive accuracy of the ECB's short-term inflation projections against predictions derived from the market prices of short-term inflation-linked swaps (fixings) in 2018-2023. We show that the predictive accuracy of fixings and the ECB projections have been very comparable during times of low and stable inflation, but during recent times of economic volatility the market prices of fixings have provided significantly more accurate predictions. We find that the efficiency of financial markets to process new information may result in more accurate short-term inflation forecasts than produced by Eurosystem insiders, and that risk premia and market inefficiencies do not seem to play a significant role in the context of short-term inflation-linked swaps. Overall, our findings suggest that making use of the information in the market prices for fixings could potentially improve the accuracy of the ECB's short-term inflation projections.

Keywords: Inflation, fixings, swaps, financial market, forecasting

JEL codes: E31, G14, G17

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1. Introduction

The European Central Bank's (ECB) macroeconomic projections, published four times a year, play a central role in the ECB's monetary policy making and communication. Included in the regular projections is the Narrow Inflation Projection Exercise (in short NIPE), which produces short-term euro area inflation forecasts over a horizon of 11 months. In the NIPE process, national central banks provide short-term forecasts of monthly frequency for overall HICP inflation and its key components for their respective countries. ECB staff aggregates these individual country inflation figures in order to obtain the euro area inflation path. Although these forecasts are not disclosed to the general public, they are fully consistent with the publicly disclosed inflation projections and closely monitored within the Eurosystem.¹

The NIPE forecasting errors have been substantial during the last years of high inflation. In this article we study whether the NIPE short-term inflation projections could be improved by making use of short-maturity inflation-linked swaps, also known as *fixings*. Given the efficiency of financial markets to process new information, market prices for inflation-linked swaps could very well provide the best attainable forecast for inflation. This could be the case especially in the short term, where timely processing of new information plays a significant role. Also, the role of (time-varying) inflation risk premia might be less important at short forecasting horizons (see, e.g., Buraschi & Jiltsov, 2005 and Chen, Liu & Cheng, 2010).

Thus, in principle, and according to the efficient-market hypothesis, efficient market prices should provide the best available forecast for inflation and no model should be able to improve it. However, market prices for fixings are not necessarily efficient, different risk premia might affect the market prices, and Eurosystem insiders (producers of the NIPE) might possess pieces of information unavailable to the market participants. Regardless, in our view, it would be a surprise if the NIPE could consistently beat the markets in the short-term and produce significantly more accurate predictions than those derived from fixings directly. For the NIPE to systematically beat fixings in predictive accuracy, either the informational advantage or the role of risk premia (or any other factor contributing to the deviation of prices from the true expectations) should be significant. According to our assessment, this seems not to be the case.²

We proceed as follows. First, we show that the inflation forward curve, derived from spot prices of inflation-linked swaps at the time of so-called NIPE cut-off date, forecasts future inflation at least as well or even better than the NIPE when measured by root mean squared errors (RMSE). By the *cut-off date* we refer to the date at which the major technical assumptions of the NIPE forecasts (e.g., interest rates and commodity prices) are fixed based on prevailing market prices. Second, as the cut-off date for the NIPE forecast usually precedes the release of the forecast by as much as two weeks, we assess how the lack of timely information available for the NIPE forecast at the time of its release affects its predictive accuracy. It turns out that at the time of the NIPE release, market expectations clearly outperform the NIPE inflation forecasts in terms of predictive accuracy, as the market prices reflect not only most of (or exactly) the same information used for producing the NIPE forecasts, but also the information accumulated during the two weeks between the cut-off date and the actual release, that the NIPE cannot make use of. This highlights the importance of timely information for the accuracy of short-term projections, and on the other hand, the efficiency of the financial markets to process such information in a timely manner. We conclude that making use of the information in inflation-linked financial

1

¹ The macroeconomic projections of the ECB, including the NIPE process, are discussed in more detail here: <u>https://www.ecb.europa.eu/press/projections/html/details.en.html</u>. There are two types of forecasting rounds: Eurosystem staff Broad Macroeconomic Projection Exercises (BMPE) and ECB staff Macroeconomic Projection Exercises (MPE). Kontogeorgos and Lambrias (2022) and Argiri et al. (2024) provide further details on the ECB's inflation projections and forecasting processes.

² The predictive accuracy of the NIPE has been studied earlier also in Oinonen and Vilmi (2021).

Forecasting inflation: A comparison of the ECB's short-term inflation projections and inflation-linked swaps

market instruments could allow the Eurosystem to produce short-term inflation forecasts of better quality than the procedures currently in use.

We alco conduct several additional exercises to understand our results better. First, we show that a simple time series model for deviation of swap prices from the true expectations might further improve the forecast, albeit only slightly. This hints in the direction of time-varying risk premia (or other factors) influencing the fixing prices, but also that the deviations from the true expectations seem small and largely insignificant.

Second, we take a look at which specific events are behind the greatest differences in the predictive accuracy of the NIPE and the swaps. On most forecasting rounds, the NIPE and the swaps seem to have performed more or less equally well, but there are some occasions on which major macroeconomic events occurred and on those occasions the swaps seem to have provided much more accurate forecasts than the NIPE. On the other hand, not once did the NIPE outperform the swaps by a significant margin. That is, while the differences between the forecasting accuracy of the NIPE and the swaps are small and difficult to assess during times of no economic upheaval, the NIPE forecasts seem prone to larger forecasting errors during times of high economic volatility.

Finally, we discuss how the market liquidity might be related to the predictive performance of the inflation-linked swaps and fixings specifically. Our analysis suggests that fixings (i.e., short-maturity inflation-linked swaps) are likely to perform even better in the future, as the market for these instruments becomes more and more efficient.

2. Inflation forward curve at the NIPE cut-off date

Markets for fixings (inflation-linked swaps of short maturities) have been available only from around the beginning of 2017, which sets some limitations to our empirical analysis. Furthermore, our proposed rudimentary approach for identifying predictable deviations in market prices from the true expectations (to be elaborated) requires the training data to be at least as long as the forecasting horizon. To this end, the subsample in all our out-of-sample assessments is set to span from the beginning of 2018 to the end of 2023. We collected all the 24 NIPE forecast releases (and their cut-off dates) during that time and compared the NIPE forecast errors to the market price implied predictions using only the market prices up to the cut-off date of the NIPE forecast. The fixing prices on the cut-off dates were acquired from Bloomberg.

The cut-off dates were used to produce the market implied predictions in order to make the forecast comparison fair in the sense that information only up to the same date was available for producing the forecasts under comparison. However, from a different point of view, this kind of comparison is not *fair* at all, since for market implied predictions there is no need for any delays between the production and the release of the forecast, but they are available in real time. We discuss the importance of such timeliness for short-term inflation projections in the next section. Moreover, the NIPE forecasters can make use of *some* information accumulated still after the technical assumptions have been fixed on the cut-off date, which actually puts the market expectations at a slight disadvantage in our forecast comparison.

Another minor issue that puts the market-based predictions to a slight disadvantage is that the fixings are not linked to Harmonized Consumer Price Index (HICP) exactly, but to HICP excluding tobacco. Fortunately, the differences between the price indices including and excluding tobacco are very small, so we may use the official inflation rate as derived from HICP as the target variable in our forecast comparison. Using HICP excluding tobacco as the target variable in our assessment would only result in marginally better performance of the market expectations and from the point of view of policy relevance, we argue that using the exact measure that is used to define the price stability objective of the ECB (HICP) is more interesting. Regardless

of their disadvantaged position in our comparison, we show below that the market-based predictions still outperform NIPE forecasts in our sample.

Table 1 reports the root-mean-squared-errors (RMSEs) of different predictions. The results are reported for the full sample and for two subsamples: the period of low and stable inflation (2018-2020) and the period of high and volatile inflation (2021-2023). For the full sample, swaps beat the NIPE at every forecasting horizon. For the full sample the differences are how-ever not statistically significant, which is not surprising given the short sample available for the analysis. The assessment of statistical significance of the differences in forecasting performance is based on Diebold-Mariano tests with a conventional significance level of 5 %.

Table 1. Root mean squared errors (RMSE) of the two forecasts produced at the time of NIPE <u>cut-off</u> dates for all horizons. If the outperformance of either forecast against the other is statistically significant on a 5% level, it is marked with *.

	2018 - 2023		2018 - 2020		2021 - 2023	
	Swaps	NIPE	Swaps	NIPE	Swaps	NIPE
h = 1	0.32	0.35	0.23	0.07*	0.39	0.49
$\mathrm{h}=2$	0.46	0.53	0.28	0.16^{*}	0.59	0.73
h = 3	0.72	0.85	0.46	0.34^{*}	0.90*	1.16
$\mathbf{h}=4$	1.03	1.19	0.49	0.38	1.40	1.67
h = 5	1.20	1.32	0.54	0.41	1.64	1.86
$\mathrm{h}=6$	1.53	1.68	0.66	0.50	2.11	2.37
$\mathrm{h}=7$	1.81	1.96	0.69	0.61	2.51	2.77
h = 8	2.24	2.36	0.73	0.66	3.23	3.42
$\mathrm{h}=9$	2.43	2.51	0.86	0.74	3.47	3.63
h = 10	2.68	2.72	0.92	0.86	3.84	3.93

The results for different subsamples however give a more nuanced picture of the differences between the forecasts. During the period of high and volatile inflation (2021-2023) the difference between the swap implied projections and the NIPE is especially prominent (to the benefit of swaps) and even becomes statistically significant for h = 3, regardless of the very short sample. This might suggest that the market prices were able to react to the rapidly changing inflation outlook faster than the central bankers producing the NIPE forecasts. Swap implied projections may thus perform better especially when the new information is coming in hot, and the volatility is high.

On the other hand, the performance of the NIPE forecasts was excellent during the period of low and stable inflation (2018-2020) and the difference between the swap implied forecasts and the NIPE was statistically significant also then (to the benefit of NIPE) for horizons up to h = 3. There are however some factors that might explain the relatively modest performance of the swap implied projections during that time. Most importantly, the markets for fixings had been around for only a few years and were far less developed and less liquid than they are today. Also, during stable times of low volatility the difference in the relative cost of useful information between the market participants and the Eurosystem insiders might change in favor of the Eurosystem insiders.

Overall, the relative forecasting performance of market prices and NIPE projections seems to be different in different times and the differences are most prominent for the shortest of forecasting horizons.

3. Inflation forward curve at the time of the NIPE release: NIPE is outdated already when released

A key advantage of the inflation swap rates is that the markets process new information more or less immediately, which is then reflected in the market prices without a delay. Hence, at the time of the NIPE release all the information up to that point can be made use of and there is no need for an early cut-off date. Next, we analyse the effect of the early NIPE cut-off date by studying the forecasting performance of the fixings around the time of the NIPE release.

To keep things simple, we do not use the exact NIPE release dates, but approximate the release date by moving the cut-off date two weeks ahead. This also gives us a convenient estimate of the time cost of the delay in the release of the NIPE forecast.

According to the results, market-based projections produced at the time of the NIPE release perform significantly better than the NIPE. The difference in performance is statistically significant for h = 2 and h = 3 in the full sample and in the latter subsample of 2021-2023 even for h = 10. In the former subsample of 2018-2020 the differences are not statistically significant. The results suggest the early cut-off date in the NIPE process to induce a significant cost to the short-term forecasting performance of the projections, essentially rendering the NIPE forecasts outdated already at the time of their release.

Table 2. Root mean squared errors (RMSE) of the two forecasts produced at the time of NIPE <u>release</u> dates for all horizons. If the outperformance of either forecast against the other is statistically significant on a 5% level, it is marked with *.

	2018 - 2023		2018 - 2020		2021 - 2023	
	Swaps	NIPE	Swaps	NIPE	Swaps	NIPE
h = 1	0.28	0.46	0.20	0.16	0.34	0.64
$\mathrm{h}=2$	0.47^{*}	0.70	0.35	0.33	0.56^{*}	0.94
$\mathrm{h}=3$	0.56^{*}	0.86	0.36	0.36	0.70^{*}	1.17
h = 4	0.92	1.24	0.47	0.41	1.24	1.74
h = 5	1.17	1.49	0.61	0.48	1.56	2.09
$\mathrm{h}=6$	1.42	1.74	0.68	0.61	1.93	2.43
$\mathrm{h}=7$	1.68	1.98	0.72	0.66	2.36	2.84
h = 8	2.18	2.44	0.83	0.73	3.10	3.53
$\mathrm{h}=9$	2.35	2.62	0.92	0.88	3.34	3.77
h = 10	2.73	2.96	0.97	0.92	4.01*	4.39

4. Additional analyses

4.1. Can we improve swap-based forecasts using econometric techniques?

In addition to using the inflation forward curve as is to forecast future inflation, we try to address the aforementioned potential deviations between market prices and true expectations (e.g., risk premia). There are different strategies for predicting such ex-ante excess-returns. For instance, some strategies approach the question from the point of view of theory-based term structure literature (e.g., Abrahams et al., 2016), whereas another simple approach is to utilise survey data (e.g., Shen, 1998).

However, as we are interested only of the predictive performance of the market prices of fixings and not of the associated premia per se, we can (and want to) remain agnostic of the specifics

of different premia (and/or any other deviations). To this end, we take a purely empirical approach to the identification of the predictable difference between prices and true expectations. We use a simple time series model to forecast the excess returns on inflation swaps and subtract these from the swap implied predictions for inflation. The model is documented in Appendix, but the basic idea is to simply make use of the observed autocorrelation in the errors of the swap implied predictions. As we show below, such an adjustment makes for slightly more accurate forecasts (in comparison to using forward rates directly) in our out-of-sample assessment, as judged by root mean squared errors, but the gains in performance are not large.

That is, we find tentative evidence of partly predictable forecasting errors for the market-based projections. After adjusting for the predictable part in the forecasting errors (Swaps + Model) we obtain uniformly smaller RMSE figures for the full sample (see Table 3) as well as for the latter subsample (2021-2023). This hints in the direction of persistent time-varying risk-premia (or other factors), which can potentially be made use of in producing more accurate inflation forecasts.

Table 3. Out-of-sample root mean squared errors (RMSE) and biases of the two forecasts produced at the beginning of every month for all horizons.

	2018 - 2023			
	RMSE		Bias	
	Swaps + Model	Swaps	Swaps + Model	Swaps
h = 1	0.42	0.42	-0.09	-0.09
$\mathrm{h}=2$	0.58	0.58	-0.21	-0.23
h = 3	0.71	0.71	-0.3	-0.33
h = 4	1.01	1.01	-0.41	-0.46
h = 5	1.24	1.25	-0.49	-0.56
h = 6	1.45	1.47	-0.58	-0.68
$\mathrm{h}=7$	1.76	1.81	-0.76	-0.87
h = 8	2.06	2.1	-0.89	-1.02
h = 9	2.39	2.44	-1.02	-1.17
h = 10	2.66	2.72	-1.16	-1.33

However, although RMSE and bias figures are both uniformly smaller for the model-based approach, the gains are very small especially for shorter horizons. Notably, the gains do get more significant for longer horizons, which could mean that correcting for differences between swap prices and true expectations is really important only for longer forecasting horizons (say, several years). Thus, for the shorter forecasting horizons of interest to our analysis, and to the NIPE process, our assessment provides tentative evidence in favour of using inflation forward curve as is, as no significant progress over those predictions can be easily made.

4.2. What drives the difference between predictive accuracy of NIPE and swaps?

Most of the time the fixings and the NIPE seem to have performed about equally well (see Figure 1). However, there are some forecasting rounds during which swaps performed significantly better than the NIPE. In this subsection, we take a closer look to what happened during these rounds (March 2022, June 2022, and December 2022). These rounds have also been highlighted in Figure 1.

The cut-off date for the March 2022 round was February 28. In principle, the NIPE should have been able to take into account the Russian invasion of Ukraine at the end of February. However, 5 Forecasting inflation: A comparison of the ECB's short-term inflation projections and inflation-linked swaps the swap markets seem to have processed this information much more efficiently and there was a significant adjustment in the swap prices immediately after the beginning of the war.

The cut-off date for the June 2022 round was May 17. Before this cut-off date there does not seem to have been any single event or macroeconomic surprise that could explain the clear overperformance of the market-based predictions. Instead, the swap prices seem to have trended upwards already from the beginning of the war in Ukraine, suggesting that there may have been multiple small signals of a faster than previously thought acceleration in inflation.

Figure 1. Differences in absolute prediction errors between the NIPE and swap implied forecasts on the NIPE cut-off dates for h = 3. Positive values indicate better accuracy of swap implied forecasts. Forecasting rounds of March 2022, June 2022, and December 2022 (discussed in the text) are bolded. As the exact NIPE figures are confidential, differences under the threshold of certain absolute value are set to zero and the scale of the y-axis is not reported.



The cut-off date for the December 2022 round was November 23. During the first half of November, fixing prices dropped significantly after the release of US October consumer price index. Inflation was below expectations in the US which was a signal for market participants about a faster than previously though slowdown in inflation in the euro area as well.

All these events highlight the efficiency of the swap markets to process all the information relevant to the inflation in a timely manner as opposed to the much more rigid NIPE process.

4.3. The market seems to be more efficient than it used to be

One potential reason for the outperformance of the NIPE in comparison to the fixings in the beginning of our sample is that the fixings had been introduced only recently and the market for them was not necessarily very liquid nor efficient back then. If this is the case, the better relative performance of the fixings in the latter subsample is not only explained by the rapid acceleration of inflation, but also by the market becoming more liquid and efficient. We take a closer look at this possibility in this subsection.

We do this by checking how 11-, 12- and 13-months swap prices vary within a month and how this variation has evolved over time. The idea behind this is as follows. 12-months swaps have

been traded since 2004 so market for them should be relatively mature. On the other hand, 11and 13-months swaps were introduced only in 2016. The market price for the 12-months swap should be close to the expected inflation during the next 12 months and the price should vary very closely with the market prices for the 11- and 13-months swaps, as the only difference between the instruments is the inclusion or exclusion of one month.

Figure 2. Within-month correlations of 12-months (M12) swap prices with 11-months (M11) and 13-months (M13) swap prices. Higher and less volatile correlation coefficients imply more efficient markets for the latter (M11 and M13).



For the reference months to stay the same, we look whether the prices for these instruments covary together within months in our sample. More efficient the market, more closely the prices of the instruments should co-move with each other within any month, and on the other hand, given there are no changes in the efficiency of the markets the co-movement should stay the same (on average) over time.

Figure 2 shows the development of within-month correlation coefficients. In the beginning of our sample, the correlation coefficients tended to be relatively low. Gradually, the correlation coefficients increased. Especially after 2021 the correlations have been very close to 1. The low correlations in the beginning of the sample are explained by the fact that there were multiple days during which the prices of 11-months and 13-months swaps did not change even though the price of 12-months swap changed. In other words, the market for these new instruments was not very active and the latest prices did not necessarily reflect the most recent information regarding the future inflation.

Our analysis suggests that the good predictive performance of the inflation-linked swaps during the latter sample was not only due to rapidly changing inflation outlook, but also due to more efficient markets for these instruments.

5. Conclusions

Fixings, or short-term inflation-linked swaps, seem to have performed just as well or even better than the ECB's NIPE projections in predicting the euro area inflation over the years 2018-2023. By making use of the information in the associated inflation forward curve in forecasting short-

term inflation, Eurosystem could have potential to improve its short-term inflation projections without any additional complexity to the NIPE process in the form of complex econometric methodology or expert judgement.

Per our analysis, the ability of the financial markets to process new information in practice without a delay is of extreme importance to the accuracy of short-term inflation forecasting. To this end, we argue that the policymakers should pay close attention to the market-based expectations of short-term inflation especially if they differ markedly from the NIPE projections. Overall, the long and winding processes involved in the production of the NIPE projections might not be well suited for the relatively short forecasting horizons considered, because of the unavoidable delays in the processing of latest information.

However, our analysis is not without its limitations. The sample available for the fixings is relatively short and it covers historically somewhat extraordinary periods. The first part of our sample (2018-2020) was highlighted by exceptionally stagnant inflation, whereas the latter part (2021-2023) was quite the opposite. Also, in the beginning of our sample the market for the euro area fixings was still developing and it is possible that the market has matured since. Hence, the beginning of our sample might not be representative of the future performance of fixings and our analysis might even underestimate the predictive power of the market prices of these instruments.

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Appendix

Here we document our rudimentary statistical approach for adjusting the market-based inflation projections to account for time-varying risk premia. This is the approach referred to as *Swaps* + *Model* in our analysis. The approach is based on making use of the observed autocorrelation in the one-step-ahead forecast errors resulting from market-based predictions of the harmonized index of consumer prices (HICP).

Let us denote HICP at time t with y_t . Then, let us denote market-based expectations at time t for HICP *i* periods ahead with x_t^i . That is, at time t the unadjusted market implied path for HICP is given by $x_t^1, x_t^2, x_t^3, \ldots$

$$\begin{pmatrix} y_{t+1} \\ x_{t+1}^1 \\ x_{t+1}^2 \\ \vdots \\ x_{t+1}^h \end{pmatrix} = \begin{pmatrix} x_t^1 \\ x_t^2 \\ x_t^3 \\ \vdots \\ x_t^{h+1} \end{pmatrix} + \begin{pmatrix} 1 \\ 1 \\ 1 \\ \vdots \\ 1 \end{pmatrix} c + \begin{pmatrix} 1 \\ 1 \\ 1 \\ \vdots \\ 1 \end{pmatrix} a \widetilde{u}_{t-1} + \underbrace{\begin{pmatrix} u_{0,t+1} \\ u_{1,t+1} \\ u_{2,t+1} \\ \vdots \\ u_{h,t+1} \end{pmatrix}}_{u_{t+1}},$$

$$\widetilde{u}_t = \frac{1}{p(h+1)} \sum_{i=0}^{p-1} \sum_{j=0}^h u_{j,t-i},$$

$$u_t \sim N(0, \Sigma).$$

Two parameters, c and a, thus capture the risk premia and need to be estimated from the data. The parameter c captures the constant bias (if any) in the market-based expectations and could optionally be fixed to zero, if deemed appropriate. The parameter a on the other hand captures the potential autocorrelation in the one-step-ahead forecast errors, u_t . The functional form of the lag structure associated with the coefficient a is simply chosen such that all the observed unadjusted forecast errors up to lag p are averaged over and if the resulting value is positive, the prediction is adjusted upwards, and vice versa. In other words, this simply makes for a parsimonious alternative for a multivariate MA-model by averaging over all the errors as opposed to estimating individual coefficients for all individual errors.

We have set p = 4 (lag length) in our analysis based on a very rudimentary visual assessment of the observed forecast errors and we have not experimented with different values of p or different functional forms of the lag structure. More sophisticated approach could certainly be developed.

The model implied best estimates for market expectations are then simply obtained as

$$E_{t}[y_{t+1}] = x_{t}^{1} + c + a\tilde{u}_{t-1}$$

$$E_{t}[y_{t+2}] = x_{t}^{2} + 2c + a(\tilde{u}_{t-1} + E[\tilde{u}_{t}])$$

$$\vdots$$

$$E_{t}[y_{t+h+1}] = x_{t}^{h+1} + (h+1)c + a\left(\sum_{i=0}^{h} \tilde{u}_{t-i}\right)$$
Expectations Market axis

Expectations-Market price

The expectations on the right-hand side are easily constructed by noting that $E[u_{j,t+i}] = 0$, for all *j* and *i* > 0. By setting c = a = 0 the expectations reduce to unadjusted market expectations.

The model can be very simply estimated by maximizing the log-likelihood function below with respect to $\theta = (c, a)'$.

$$\begin{split} l(y \mid \theta) &= \sum_{t=1}^{T} \sum_{j=1}^{h+1} \log N(\varepsilon_{j,t}(\theta) \mid 0, 1), \\ \varepsilon_t &= C^{-1} u_t, \\ \Sigma &= CC' = \frac{1}{T-1} \sum_{t=1}^{t} u_t' u. \end{split}$$

Note that C can simply be a lower triangular part of the Cholesky decomposition of the variance-covariance matrix of the errors, which can itself be estimated by taking the cross-product of the errors as written above.

However, we obtained much more stable estimates in our short and volatile sample after taking changes in volatility into account by fitting a parsimonious GARCH-type process to the errors. Note that this affects the resulting estimates for the market expectations only through different parameter estimates of c and a and only requires for a slight adjustment (below) to the log-likelihood function used to estimate the model:

$$l(y \mid \theta) = \sum_{t=1}^{T} \sum_{j=1}^{h+1} \left(\log N(\varepsilon_{j,t} v_t^{-1}(\theta) \mid 0, 1) - \log v_t(\theta) \right),$$
$$v_t^2(\theta) = \sqrt{(1 - \alpha - \beta) + \alpha v_{t-1}^2 + \beta (\frac{1}{h+1} \sum_{j=1}^{h+1} \varepsilon_{j,t}^2)},$$

where the maximization now happens with respect to $\theta = (c, a, \alpha, \beta)'$.

BoF Economics Review

2022	No 1	Norring, Anni: Taming the tides of capital – Review of capital controls and macroprudential policy in emerging economies
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	No 6	Mäki-Fränti, Petri: The effects of age and cohort on household saving
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