EUROPEAN CENTRAL BANK

EUROSYSTEM

Central Banking economic modelling for forecasting and policy analysis in times of uncertainty

Preparing the future

Università Roma Tre
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Disclaimer

The opinions expressed in this presentation are my own and do not necessarily reflect those of the European Central Bank or the Eurosystem

Overview

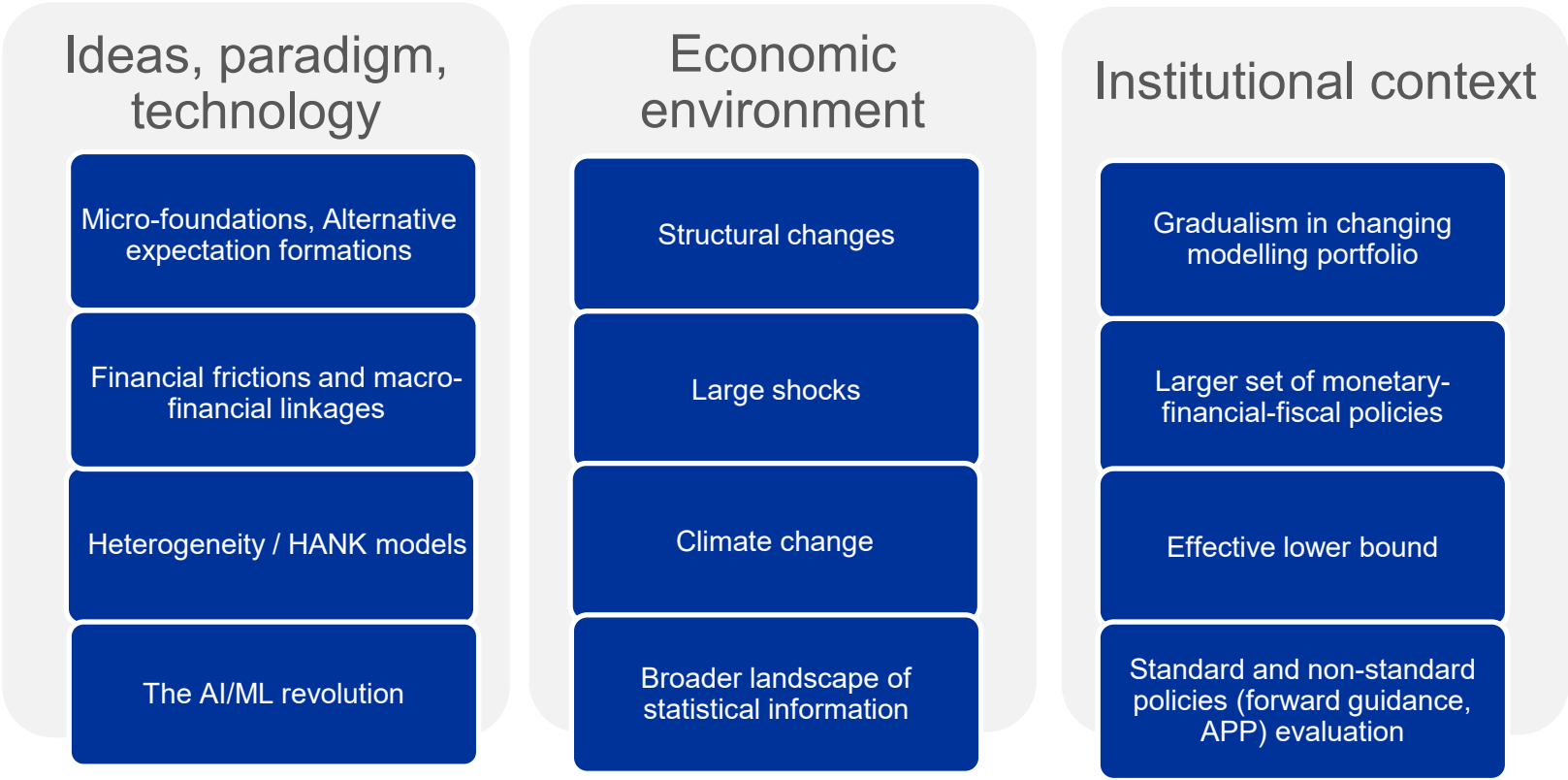
1. Central banking models: Theory and practice
2. An uncertain landscape: Old shocks, new development, forecast errors
3. Navigating ambiguity: Scenario and risk analysis
4. End of an era? The future of (central banking) modelling
5. Conclusion: Preparing the future

1

Central banking models

Theory and practice

What drives progress in central banking modelling



Source: Ciccarelli et al, ECB macroeconometric models for forecasting and policy analysis, ECB OP 344, 2024

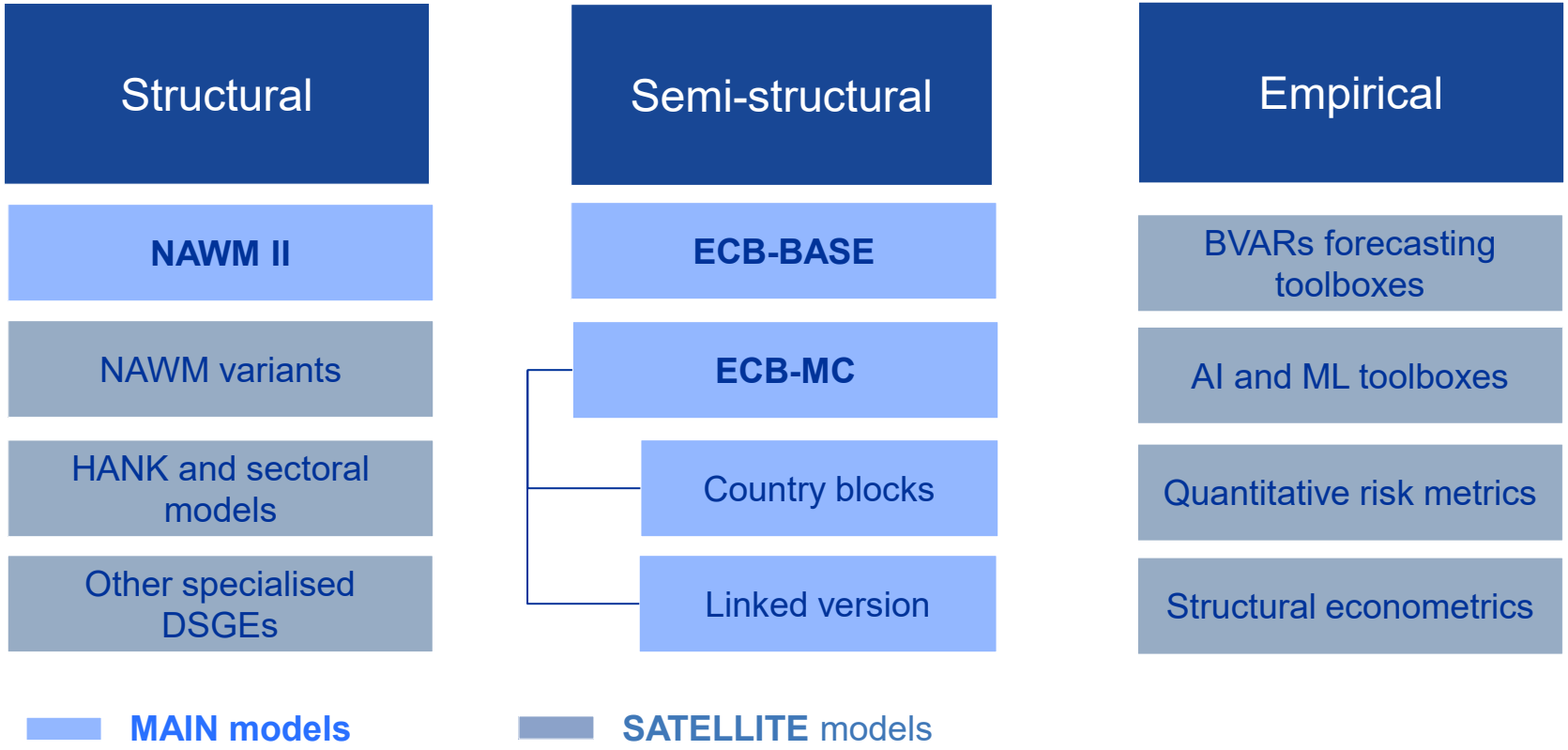
Should Central banks have one or many models for a given purpose?

- No aspiration to build a model that includes everything
- Need for continuity in the assessment while keeping changing and including new channels and frictions
- Resonance or dissonance between academic research and modelling at policy institutions?

Academic research	Policy modelling
Simple and stylised	Realistic and granular
Deep theoretical foundations	Robust to structural uncertainty
Original and strong policy prescriptions	Continuity and consistency with policy paradigm

➢ **ECB approach: develop and maintain a suite of models and tools for complementary purposes**

Broad ECB core macro-modelling portfolio for forecasting and policy analysis

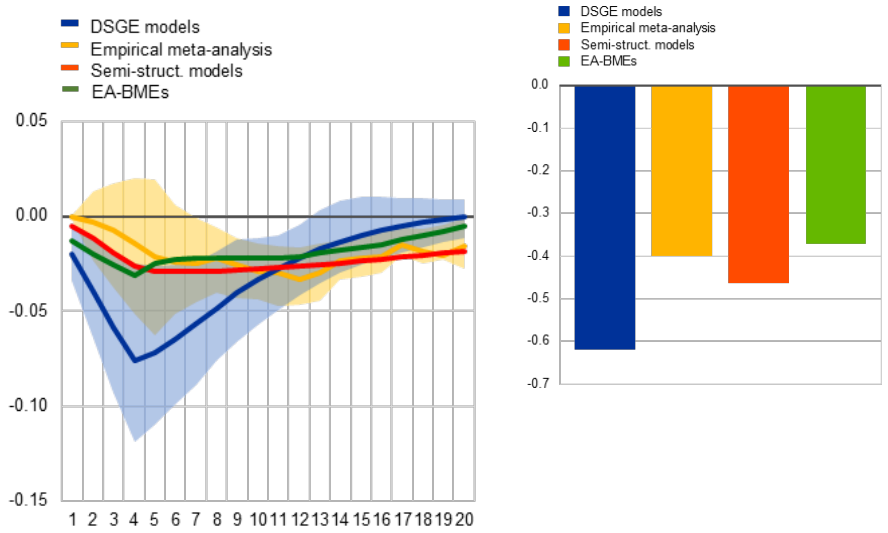


Source: Ciccarelli et al, ECB macroeconometric models for forecasting and policy analysis, ECB OP 344, 2024

Model validation: Benchmarking monetary policy shock in our models against literature

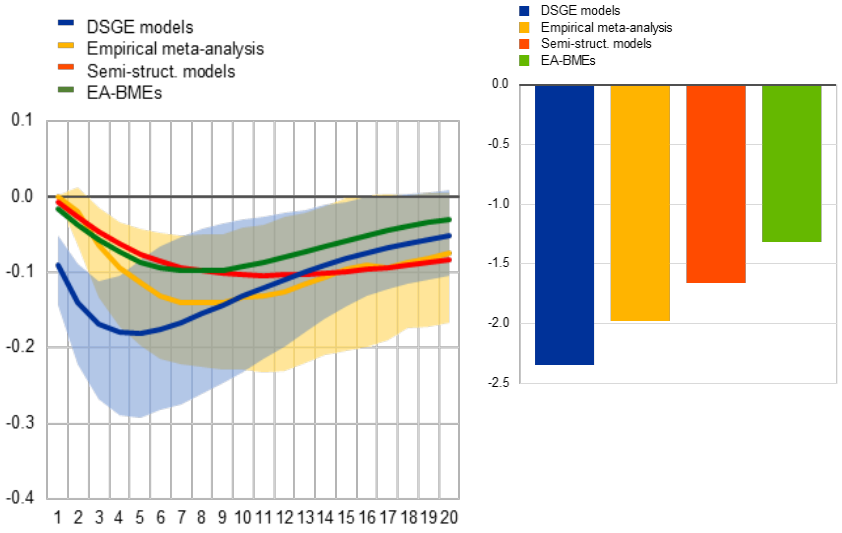
Annual inflation

(p.p.deviations from baseline and cumulated effects)



Output

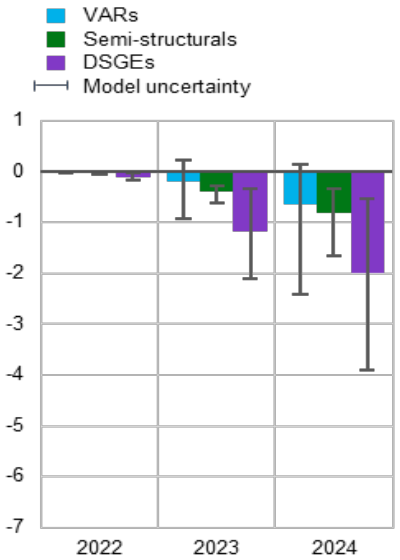
(p.p. deviations from baseline and cumulated effects)



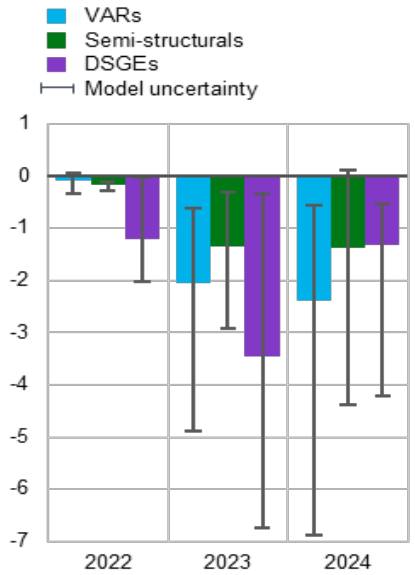
Source: ECB Occasional Paper on "Monetary Policy Transmission - A reference guide through ESCB models and empirical benchmarks". ECB, November 2025, No. 377.
Notes: EA-BMEs model builds on the Eurosystem's BMEs while incorporating a forward-looking financial block à la Dornbusch. This extension endogenizes monetary policy, long-term interest rates and the exchange rate. It uses forward-looking expectations for the latter two variables and assumes the same Taylor rule as ECB-BASE for the policy rate. The model equations link other endogenous variables to exogenous shocks using the official BMEs, which are updated annually.
IRFs have been harmonised to reflect the effects of a 25 basis points conventional monetary policy shock. Simulation horizon in quarters. The yellow shaded area represents the median from the 68% confidence intervals of the primary studies in the meta-analysis. The blue shaded area represents the 84th–16th percentile range of collected ESCB DSGE models' impulse response functions

Recent effectiveness of monetary policy through the lens of models

Annual inflation
(year-on-year changes, percent)



Output
(year-on-year changes, percent)



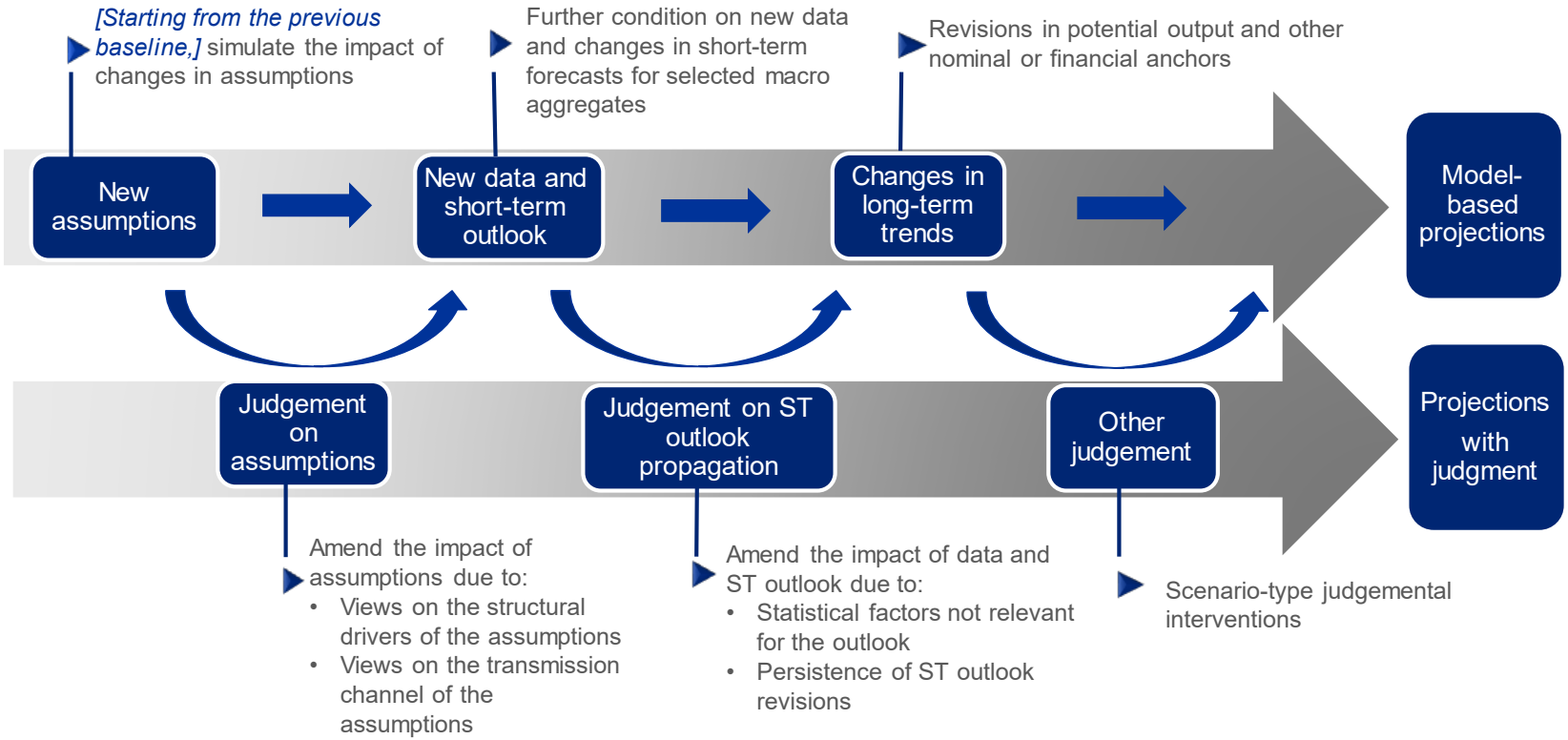
Source: ECB staff calculations based on M. Enzinger, S. Gechert, P. Heimberger, F. Prante, D. Romero, “The overstated effects of conventional monetary policy on output and prices” (forthcoming) for empirical VAR models, and on the average response of surveyed ESCB's semi-structural and DSGE models. Model uncertainty refers to the 68% confidence interval around the central estimate for VAR models, 16-84 interpercentile range for DSGE models' responses, and the min-max range for semi-structural models' responses.

Policy use of the ECB macro-modelling portfolio

Economic projections	• Forecasting with judgment and model-based projection narratives for the euro area as well as for the largest euro area countries
Sensitivity, risk, and scenario analysis	• Conditional predictive densities from forecasting models • Sensitivity of baseline to key assumptions (Oil, FX, Fiscal, Financial) • Risk balance for the (B)MPEs • Scenario analysis of relevant macroeconomic contingencies
Policy analysis	• Impact study of monetary policy options • Optimal and robust monetary policy analysis • Strategic issues related to monetary-fiscal-financial policy mix in the euro area

Source: ECB macroeconometric models for forecasting and policy analysis

Final forecasts are not only based on models: The role of judgment



Source: ECB macroeconometric models for forecasting and policy analysis

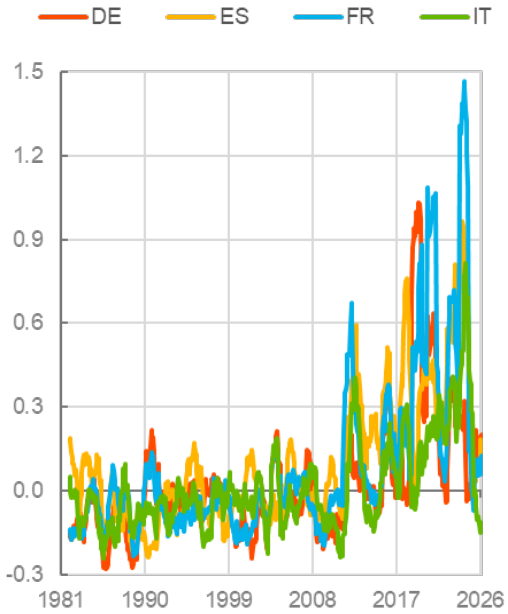
2

An uncertain landscape

Old shocks, new shocks, forecast errors

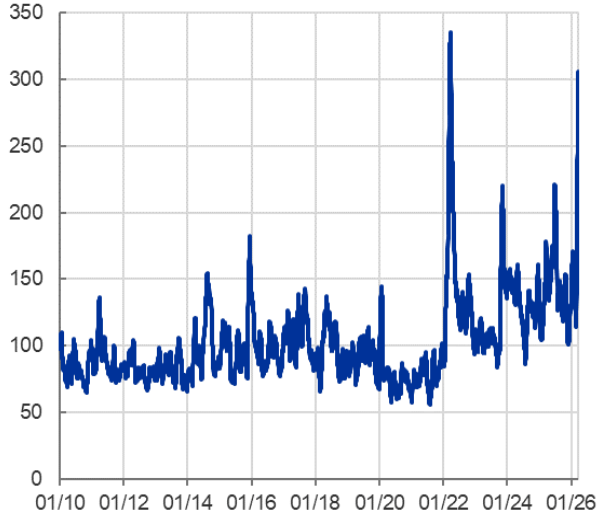
Importance of supply shocks since the Covid pandemic

Extreme weather events
(12-month rolling average index)



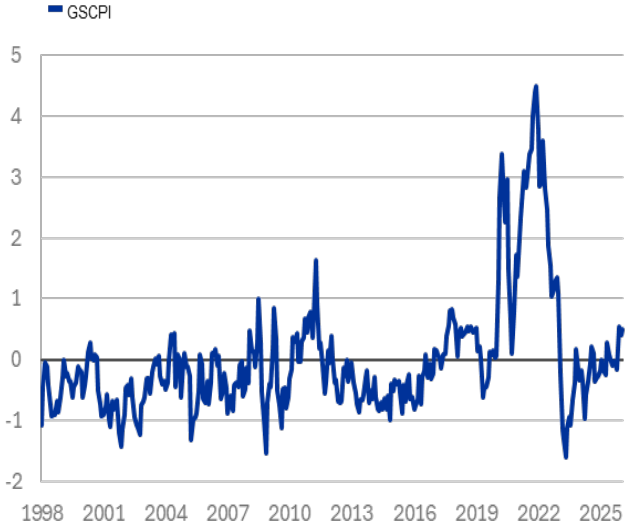
Sources: IFAB and ECB staff calculations.
Notes: The European Extreme Events Climate Index (E3CI) provides a general overview of weather-induced hazards by combining seven components: Extreme Max and Min Temperature, Drought, Extreme Precipitation, Hail, Fire, Extreme Wind. A value over 1 indicates an extreme weather event. The index shows a standardised anomaly with respect to the reference values (based on data ranging from 1981-2010). Latest observation: March 2026.

Geopolitical risk
(index)



Source: Caldara and Iacoviello (2022).
Notes: 30-day moving average of the daily geopolitical risk index by Caldara and Iacoviello (2022). The index is based on newspaper articles and is constructed by counting the number of articles related to adverse geopolitical for each month (as a share of the total number of news articles). Latest observation: 23 March 2026.

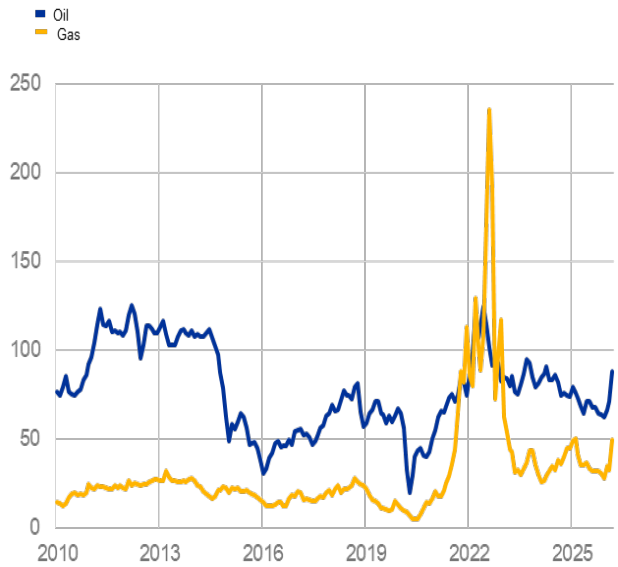
GSCPI
(Global Supply Chain Pressure Index)



Sources: Federal Reserve Bank of New York.
Notes: The GSCPI integrates a number of commonly used metrics with the aim of providing a comprehensive summary of potential supply chain disruptions. The GSCPI is a standardized index expressed in standard deviations from the mean of 0. Latest observation: February 2026.

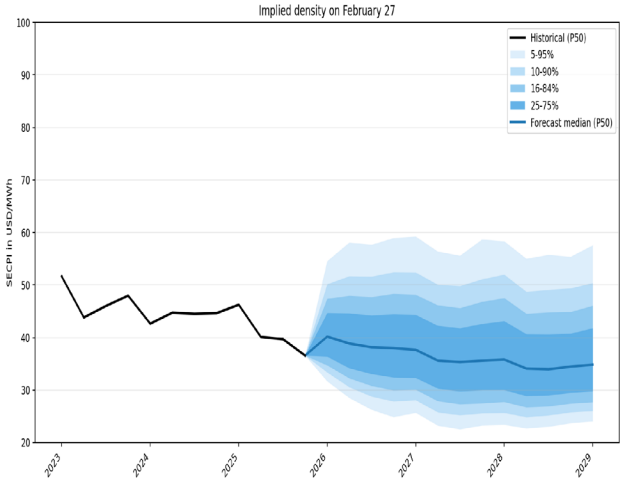
Old shocks, new developments: Energy

Oil and gas prices
(oil: USD per barrel, gas: EUR per MWh)



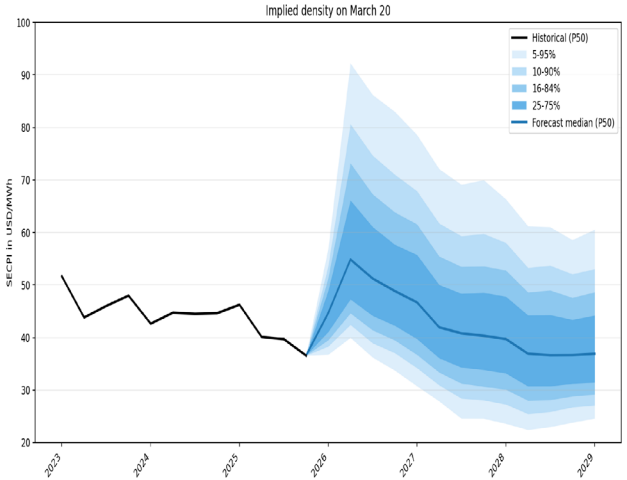
Source: ECB Projection Database.
Latest observation: March 2026.

SECPI pdf Pre-War
(index)



Sources: ECB Staff calculations
Notes: Fan chart of the Synthetic Energy Consumer Price Index (SECPI), values in levels. The SECPI is computed as a weighted average of oil and gas option-implied probability density functions. The figure displays the median of the forecast together with the uncertainty quantiles. The chart incorporates information up to the close of financial markets on 27 February, the day before the outbreak of the 2026 Iran war.

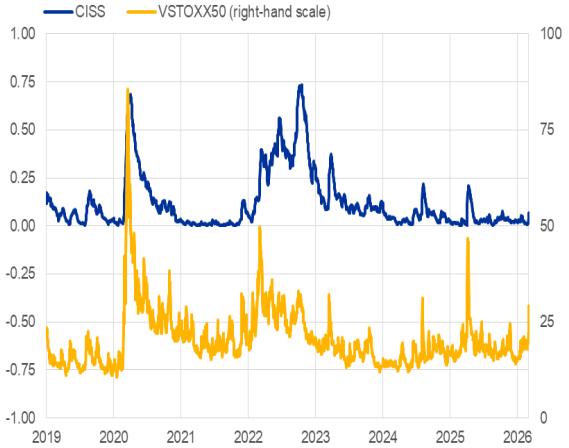
SECPI pdf Post-War
(index)



Sources: ECB Staff calculations
Notes: Fan chart of the Synthetic Energy Consumer Price Index (SECPI), values in levels. The SECPI is computed as a weighted average of oil and gas option-implied probability density functions. The figure displays the median of the forecast together with the uncertainty quantiles. The chart incorporates information up to the close of financial markets on 20 March.

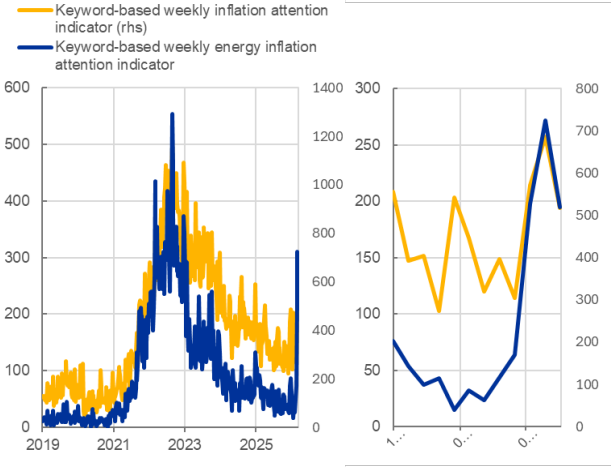
Other Measures – Financial Volatility and Attention Index

Financial Market Uncertainty



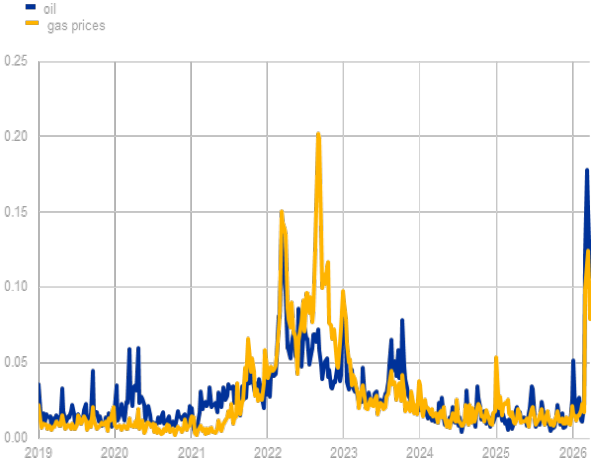
Sources: CBOE Global Markets and ECB staff calculations.
Notes: The VSTOXX (EURO STOXX 50 Volatility Index) is a financial benchmark that measuresmarket expectations of near-term volatility in the Eurozone's leading blue-chip index, the EUROSTOXX 50, where higher values signal greater expected uncertainty. The CISS is a composite indexof financial stress across key market segments, where higher values reflect more severe andbroadly-based systemic stress.

Inflation Attention Index



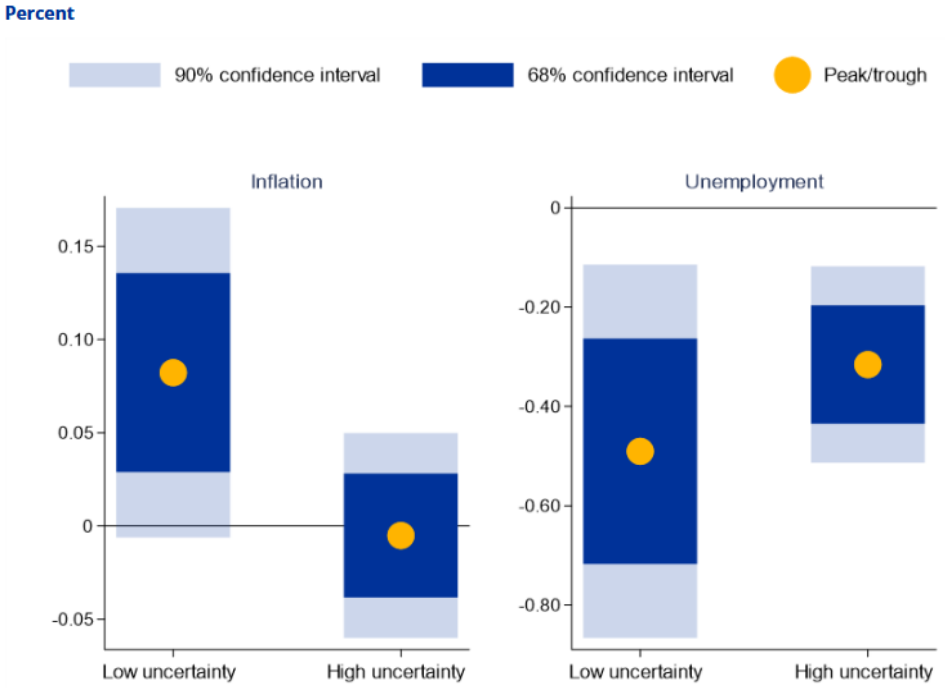
Sources: Dow Jones Factiva and ECB calculations
Notes: Inflation and energy inflation attention in the news are calculated as weekly averages of the daily index. The daily index is based on the fraction of articles mentioning keywords related to inflation and energy inflation and is normalised such that the average over the period 1 January 1995 to 31 December 2011 equals 100. For the methodology see Aarab et al. (2025) . The latest observations are for 16 March 2026 for both inflation and energy inflation attention in the news.

Oil and Gas Attention Index



Sources: Dow Jones Factiva and ECB calculations.
Notes: The figure reports weekly news-based attention indices for oil prices and gas prices in the euro area. Each index is based on the fraction of articles classified as related to the respective topic using a deep-learning approach that identifies semantically relevant content. Higher values indicate a larger share of articles classified as relating to the respective topic. The latest observations are for 25 March 2026..

Economic uncertainty weakens monetary policy transmission



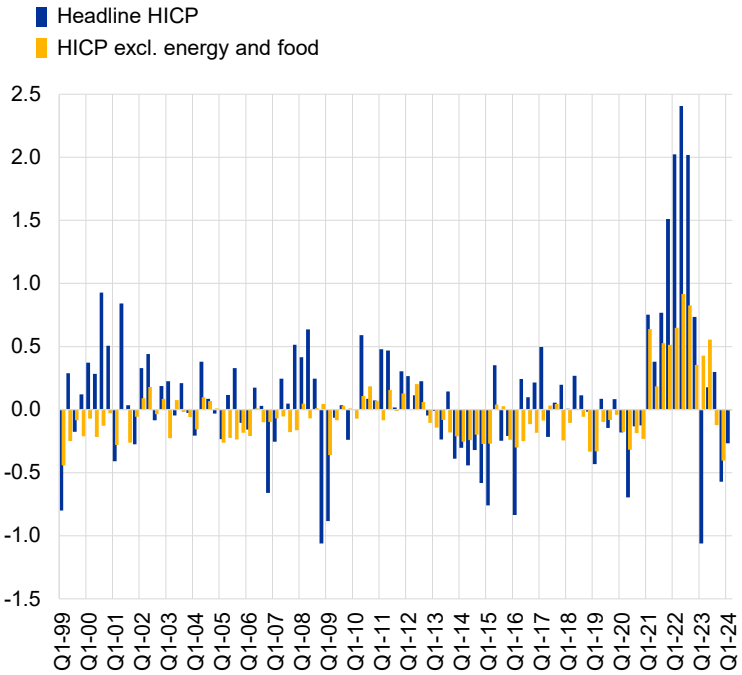
- **High uncertainty dampens monetary policy impact:** households and firms delay borrowing and investment, weakening transmission channels
- **Policy implication:** central banks may need stronger or more persistent actions to achieve desired economic outcomes

Source: ECB staff calculations.
Notes: Peak impulse responses to a 100-basis point monetary policy shock estimated using local projections, with the interquartile range indicator in its upper ("high uncertainty") and lower ("low uncertainty") decile. Monetary policy shocks are identified using the "poor man's sign restrictions" as in Jarociński and Karadi (2020). The response peaks at the 25-month horizon for inflation and the 12-month horizon for unemployment. The local projections control, among other things, for the interquartile range of euro area industrial production (excluding Ireland), our proxy for economic uncertainty, and its interaction with monetary policy shocks. The uncertainty indicator is endogenously obtained by jointly estimating different quantiles of industrial production as a function of industrial production lagged quantiles and a set of control variables, following Falconio and Manganelli (2025). The outcome variables are the euro area Harmonised Index of Consumer Prices (left panel) and unemployment (right panel). All variables are in log-levels. All data are at monthly frequency for the 2002m1-2025m4 period. Standard errors are derived from the Newey and West (1987) estimator to account for autocorrelation and heteroskedasticity.

Inflation forecast errors: Uncertainty or model inadequacy?

One-quarter ahead errors for HICP and HICPX

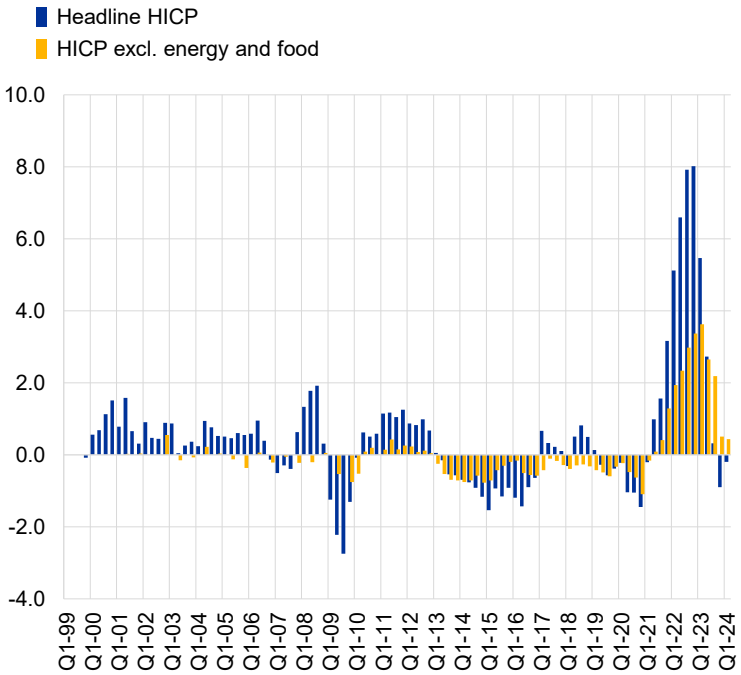
(percentage points)



Sources: Eurostat, ECB, ECB Staff calculations.
Notes: An error is defined as the outturn for a given quarter minus the projection made for that quarter in the previous quarter.

Four-quarter ahead errors for HICP and HICPX

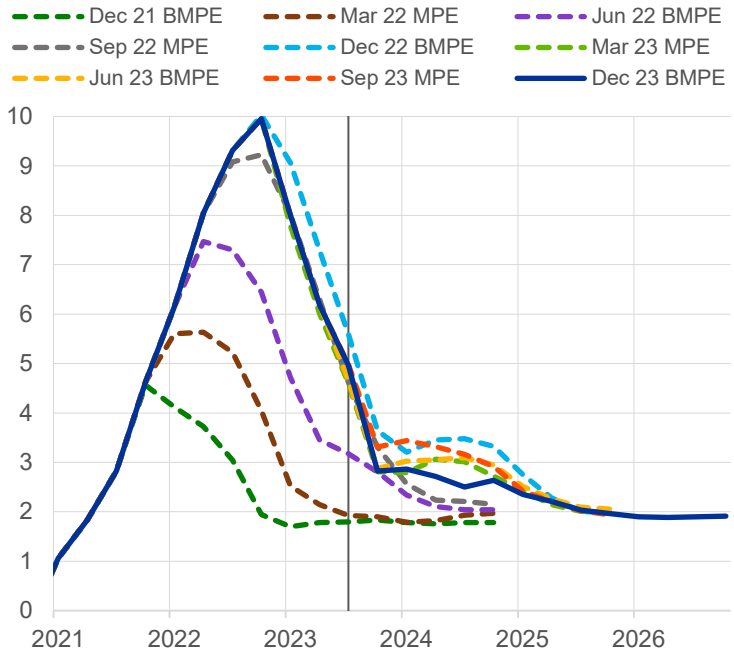
(percentage points)



Sources: Eurostat, ECB, ECB Staff calculations.
Notes: An error is defined as the outturn for a given quarter minus the projection made for that quarter four quarters earlier.

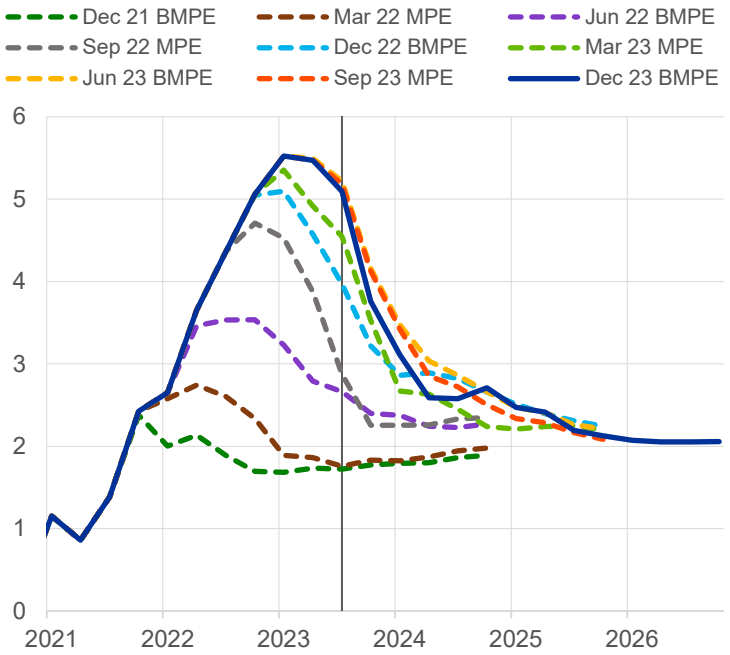
Inflation in the euro area: recent developments and ECB/Eurosystem Staff projections

HICP inflation
(annual % changes)



Source: ECB and Eurosystem Staff (Broad) Macroeconomic Projections Exercises ((B)MPE).

HICP inflation excl. energy and food
(annual % changes)

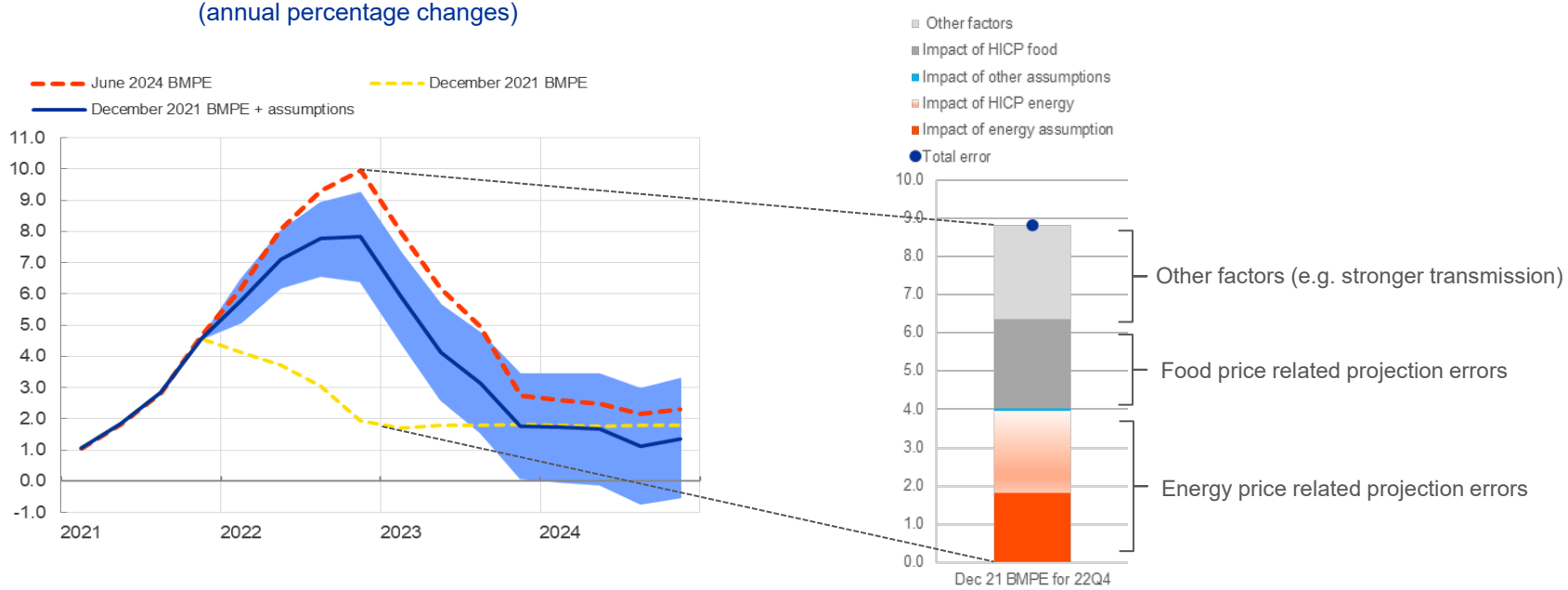


Source: ECB and Eurosystem Staff (Broad) Macroeconomic Projections Exercises ((B)MPE).

Could we have done better with one of our core models? YES

Dec 2021 HICP inflation projections: with and without perfect foresight about assumptions

(annual percentage changes)



Source: ECB-BASE, Eurostat, December 2021 BMPE and September 2023 MPE.
Note: 'December 2021 + assumptions' is simulated using the December 2021 BMPE baseline, but imposing the paths of HICP energy, HICP food and other technical assumptions available in December 2024 BMPE. The distribution is obtained by bootstrapping residuals of all endogenous equations and excluding equations for technical assumptions. Bands show 95% uncertainty interval.

The ECB has been quite transparent on mistakes

For forecast accuracy of BMPE projections and related material see these publications:

1. An update on the accuracy of recent Eurosystem/ECB staff projections for short-term inflation, ECB Economic Bulletin, Issue 2/2024.
2. What explains recent errors in the inflation projections of Eurosystem and ECB staff?", *Economic Bulletin*, Issue 3, ECB, 2022.
3. The performance of the Eurosystem/ECB staff macroeconomic projections since the financial crisis, *Economic Bulletin*, Issue 8, ECB, 2019.
4. A full database of past Eurosystem/ECB staff macroeconomic projections is available to the public via the ECB Data Portal, which allows researchers to easily assess the performance of these projections. The processes and tools used to produce staff projections are described in a guide available on the ECB's website.
5. An updated assessment of short-term inflation projections by Eurosystem and ECB staff", *Economic Bulletin*, Issue 1, ECB, 2023.

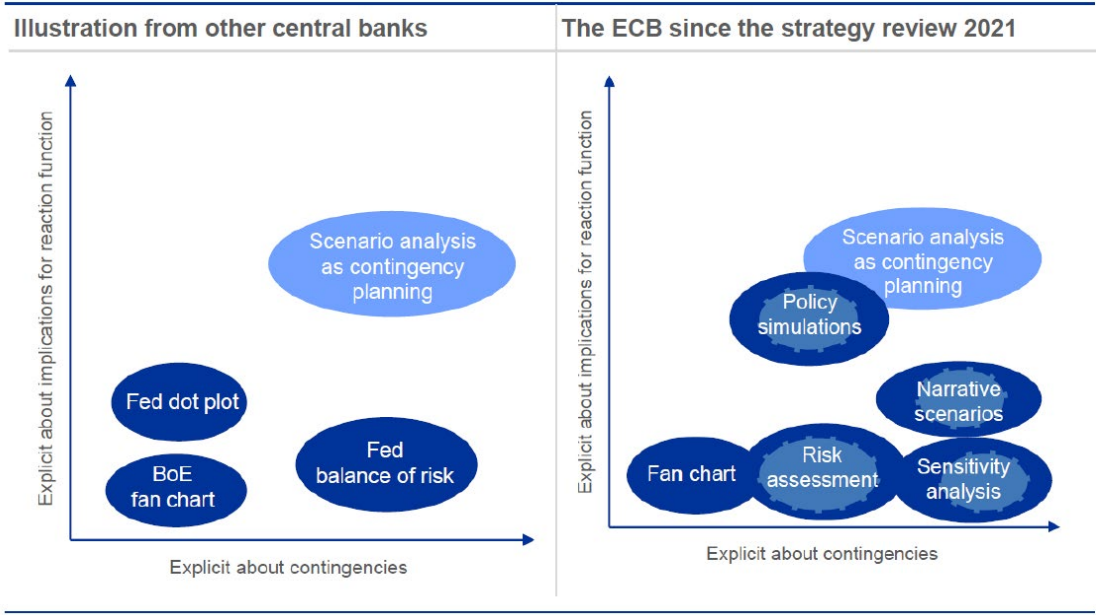
3

Navigating ambiguity

Scenario and risk analysis

Tail risks endogenous to policy decisions: Importance of scenario analysis

Risk/uncertainty and policy implications



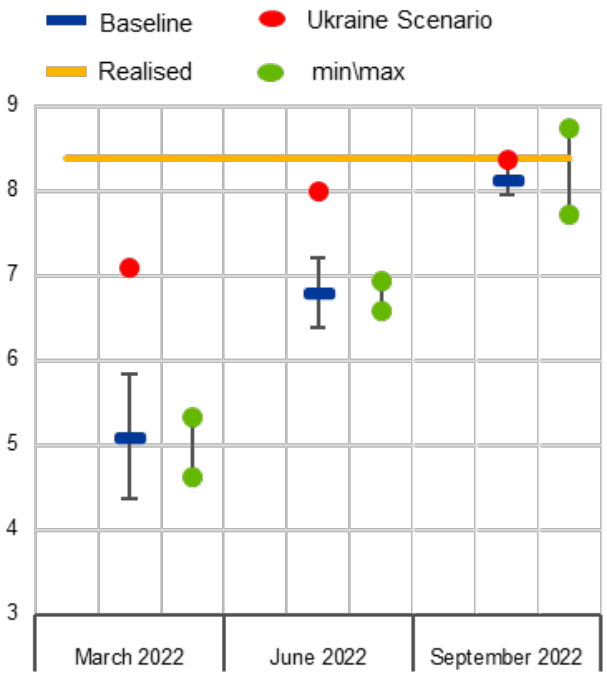
Source: ECB staff.
Notes: In the right panel, the bubbles with shaded colour stand for elements that have been expanded since the 2021 strategy review.

Source: "Report on monetary policy tools, strategy and communication", ECB OP no 372

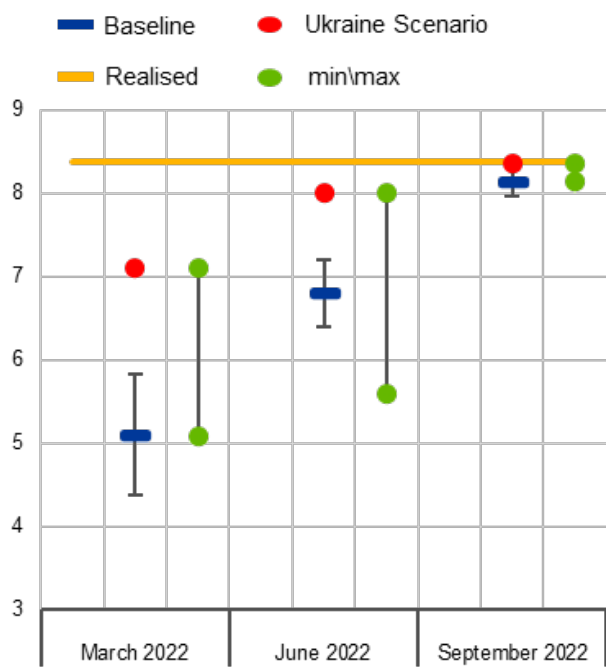
- Modal forecast are 'problematic' with large and unexpected shocks and no longer sufficient for policy decision
- The 2024 Bernanke review at the Bank of England called for more prominence to be given to scenario analysis in internal discussions and external communication and for lower emphasis on modal forecasts
- The aim is not simply to identify relevant contingencies but also to assess the appropriate policy reaction under each contingency (risk management approach)

Baseline projection, scenarios, and sensitivity analysis for inflation in 2022

Sensitivity analysis for 2022



Alternative scenarios for 2022



Sources: ECB/Eurosystem staff projections and ECB staff calculation.
Notes: The ranges surrounding the respective baseline refer to a measure of uncertainty based on past projection errors, after adjustment for outliers, showing the 90% probability that the outcome of HICP inflation will fall within this interval. Panel a): Max and Min refer to the highest and lowest outcome from various scenarios including scenarios on the war in Ukraine, higher inflation expectations, real wage catch up etc. Panel b) Max and Min refer to the highest and lowest outcome from sensitivity analyses related to energy prices, exchange rates and market interest rates.

Source: Exploring an uncertain future with the help of scenarios, ECB blog, 15 January 2025

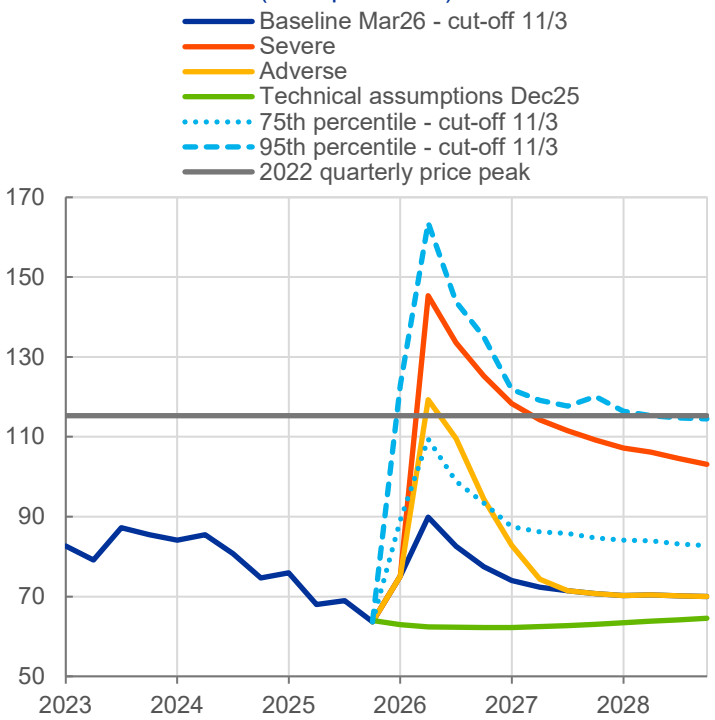
Narrative of the baseline and alternative scenarios in the March 2026 projections

	Persistence of acute energy supply disruptions	Uncertainty	Indirect and second-round effects on inflation	Fiscal and monetary policy reactions
Baseline	**No explicit assumption** on the duration of the conflict or destruction of energy infrastructure Energy prices follow **latest technical assumptions** (cut-off 11 March 2026)	In line with the **observed increase** in the VIX index (4.4 points between 27 February 2026 and the cut-off date of 11 March 2026)	**Limited upward adjustment based on judgement** to account for possible larger impacts compared with the standard model elasticities due to the size of the energy shock	None beyond the policies included in the baseline assumptions on short-term rates + fiscal policy assumptions following usual rules
Adverse scenario	**Acute energy supply disruptions** But no significant further destruction of energy infrastructure	Increase in the VIX index of **10 points with a fast reversal** in Q3 2026 towards the Q4 2025 level	Stronger **impact on other prices (food, goods, services) and wages due to non-linearities (as seen after the 2021-22 episode)**	None beyond the policies included in the baseline
Severe scenario	Even **more acute energy supply disruptions** and **significant further destruction of energy infrastructure**	Increase in the VIX index of **14 points,** remaining **significantly more elevated** compared with the adverse scenario until end-2027	**Stronger non-linearities lead to sizeable indirect and second-round effects**	None beyond the policies included in the baseline

Middle East conflict scenarios: commodity price assumptions, March 2026 MPE

Oil prices

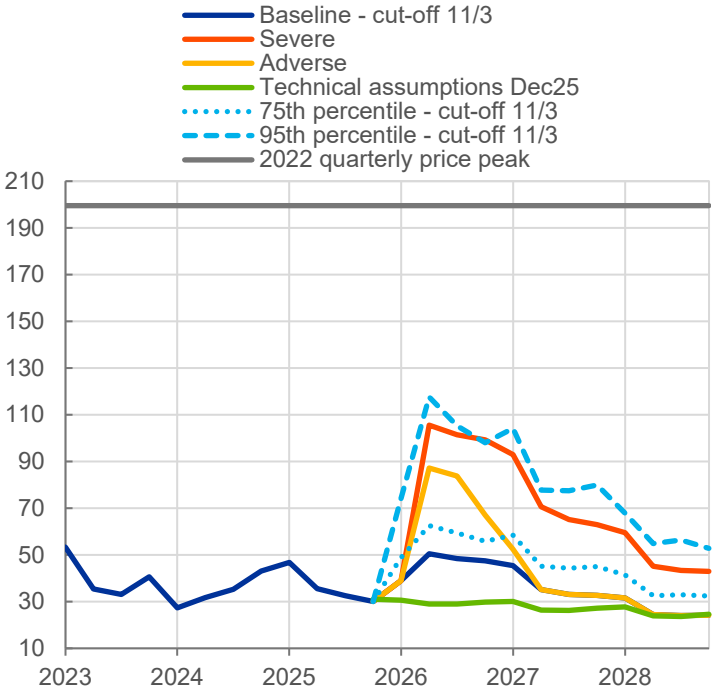
(USD per barrel)



Sources: Refinitiv and ECB staff calculations.
Notes: The 2022 price peak refers to second quarter of 2022. The latest observations are for 11 March 2026.

Gas prices

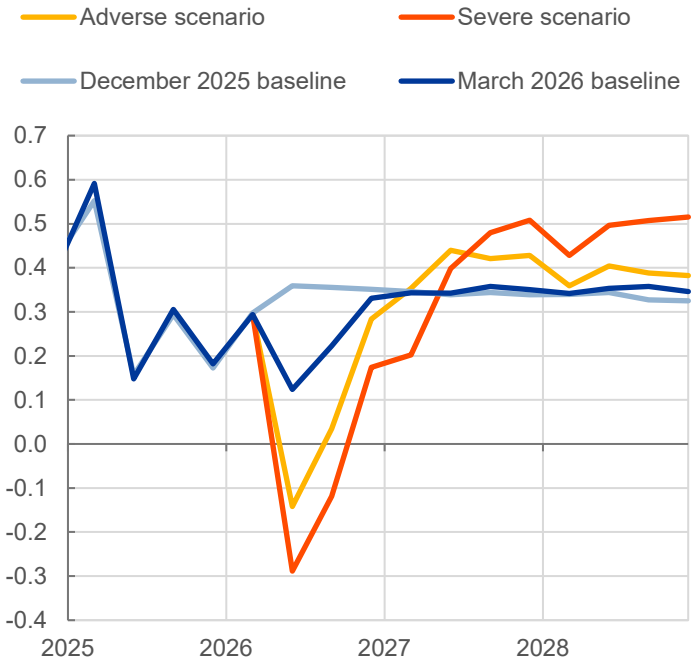
(maximum percentage deviation)



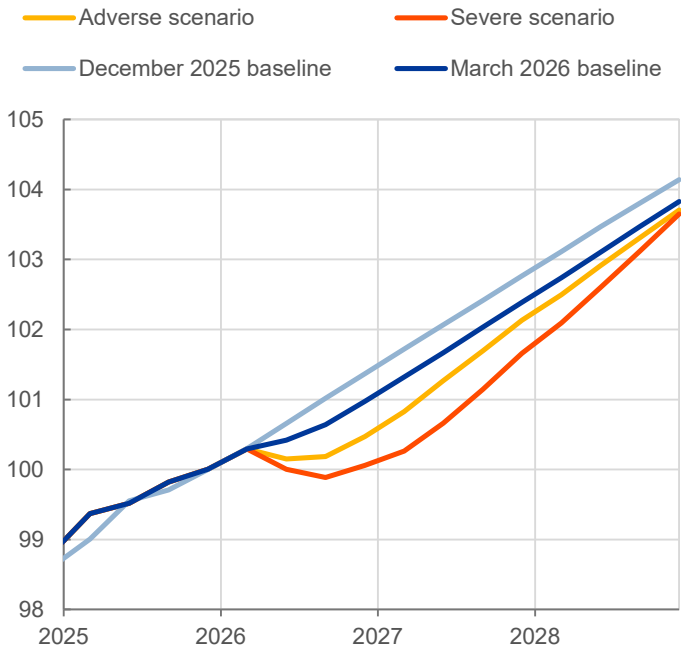
Sources: Refinitiv and ECB staff calculations.
Notes: The 2022 price peak refers to third quarter of 2022. The latest observations are for 11 March 2026.

Growth in the baseline and adverse and severe scenarios

Real GDP growth
(quarter-on-quarter growth rate)



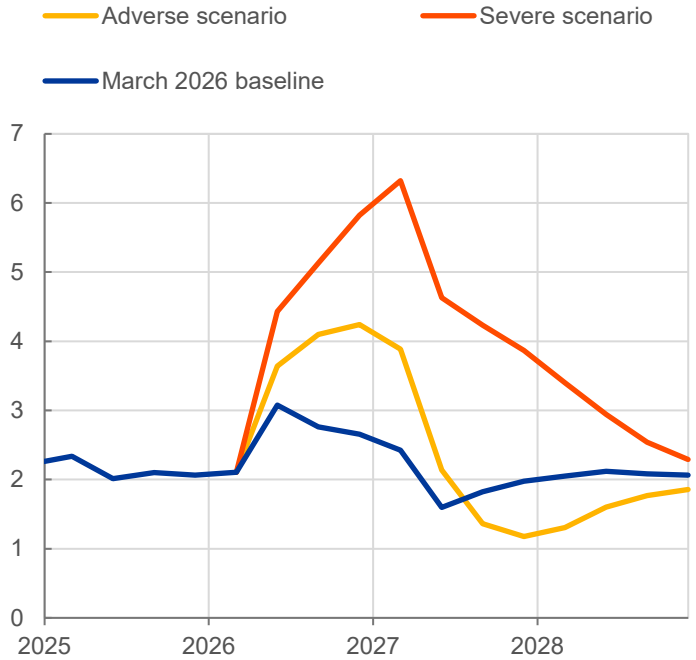
Real GDP
(index level; 2025Q4=100)



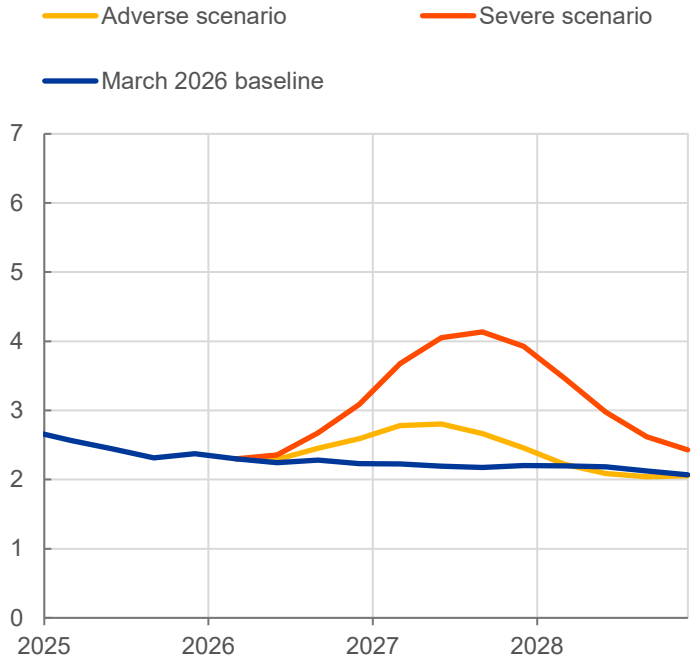
Sources: Simulations using the ECB-BASE model and ECB staff calculations.
Notes: Simulations are conducted with the ECB-BASE model under a forecast setting with backward-looking expectation formation and with exogenous monetary and fiscal policy assuming that the shock starts in the second quarter of 2026. The overall impact on euro area economic growth and inflation includes energy, uncertainty and trade effects (foreign demand, competitors' prices and exchange rates, computed in the ECB-Global model). The impact of the uncertainty shocks on GDP is estimated outside the model using an empirical framework, namely a BVAR model, and performing conditional forecast exercises on different paths for the VIX.

Inflation in the baseline and adverse and severe scenarios

HICP inflation
(annual percentage changes)



HICP excluding energy and food inflation
(annual percentage changes)



Sources: Simulations using the ECB-BASE model and ECB staff calculations.
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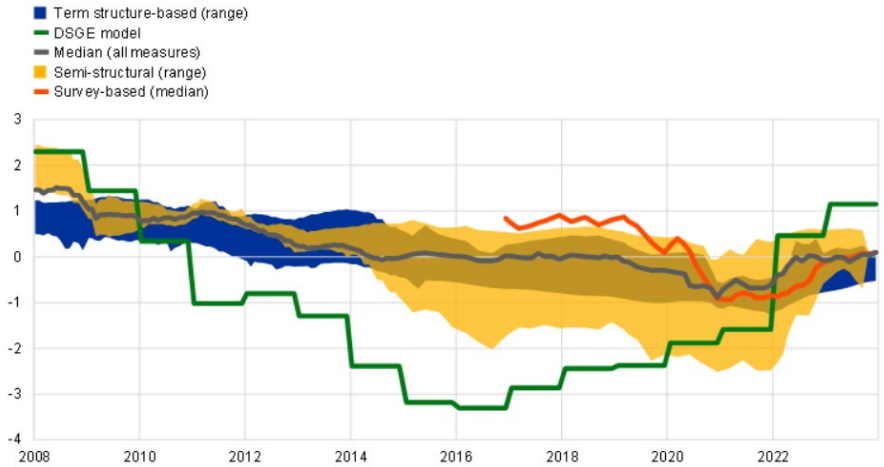
Recent disruptions to long-run trends depressing interest and inflation rates

Real natural interest rate estimates

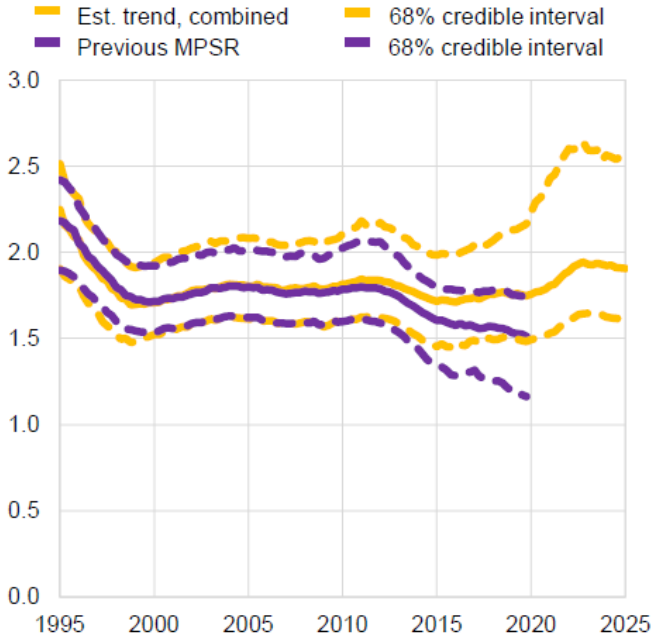
(percentage points)



Sources: ECB Economic Bulletin, Issue 1/2024

Estimated trend inflation

annual percentage changes



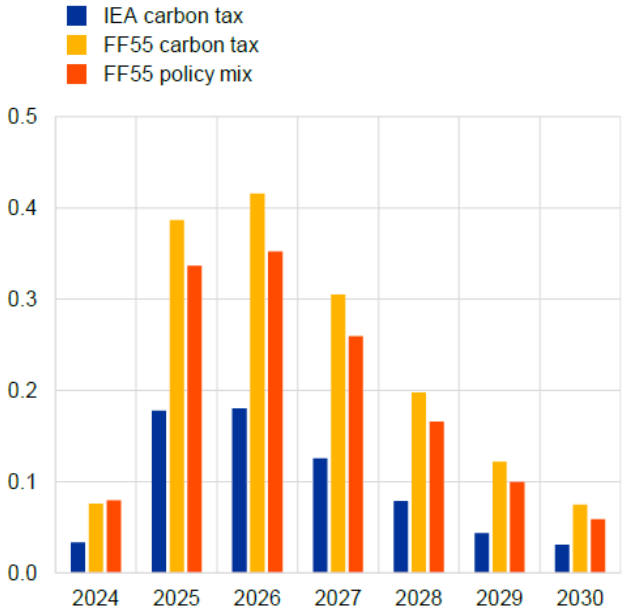
Sources: 2025 MPSA

Notes: Estimated trends from a Phillips curve linking inflation gap to output gap. The Phillips curve follows the approach by Chan, Clark and Koop (2018) and allows for time-varying coefficients and variances. In the “anchored” version the trend is linked to the five-year-ahead inflation expectations from the SPF, see also Banbura and Bobeica (2023); The latest observations are for the first quarter of 2025 and for the fourth quarter of 2019.

Policy and fiscal challenges adding on inflation risk

Green transition policies: impact on inflation

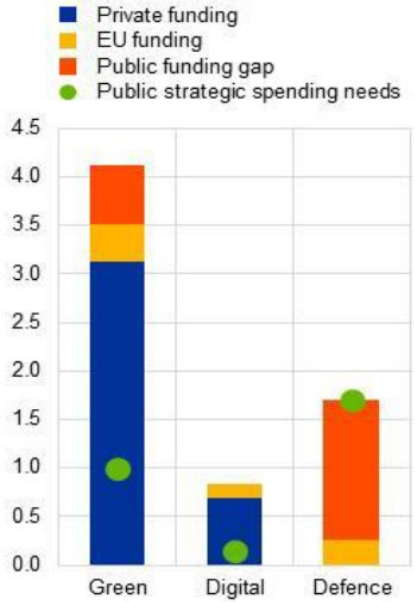
(percentage points deviation from baseline with existing measures)



Sources: 2025 MPSA
Notes: The IEA carbon scenario is based on the International Energy Agency's 2022 World Energy Outlook and involves carbon taxes increasing steadily to $140/ tonne by 2030. This is insufficient to meet the fit-for 55 target. Two further scenarios are consistent with the fit-for-55 target, one using just carbon taxes and another using a policy mix that proxies the effect of regulation by an increase in total factor productivity of the "clean" energy sector and through higher elasticities of substitution between "dirty" and "clean" energy.

Public vs private strategic spending needs

% of GDP, additional, average annual 2025-31



Sources: 2025 MPSA
Notes: The chart shows the European Commission's official estimates for green and digital investment plus defence expenditure over 2025-31. The choice of this period accounts for the reform of EU fiscal governance, which envisages the adoption by Member States of fiscal-structural plans lasting up to seven years (2025-31). Additional strategic spending needs are defined as the difference between total needs (with cut-off date of 12 March 2025) and historical benchmarks (for green investment the average for the period 2011-20, for digital investment the average for the period 2014-20, and for military expenditure 2024).

4

End of an era?

The future of (central banking) modelling

Where do we stand today? A crossroad

From single models to hybrid systems:

Traditional approach

- One main model (DSGE / VAR)
- Point forecasts
- Limited data

Current reality

- Suite of models
- Density forecasts
- Big Data + ML methods + data-rich tools

➢ Scenario and risk analyses

ML methods:

- significantly improve short-term **forecasting accuracy**
- **capture nonlinearities and & regime changes**
- handles **large, high-frequency datasets**
- **But** :
  - ➢ Limited economic interpretability
  - ➢ Weak for policy counterfactuals

Empirical reality: AI as Forecast Engine

Nonlinear & distributional forecasting

- Quantile methods (QRF) → **full distributions**
- ML models capture:
  - nonlinearities
  - regime changes
  - tail risks

High-dimensional data & real-time signals

- Hundreds of predictors (financial, global, high-frequency)
- Methods:
  - LASSO → variable selection
  - Random Forests → nonlinear interactions

Foundation models (emerging)

- Trained on many time series
- Enable **cross-country / cross-variable learning**

Text as macro data

- Central bank speeches/news/reports
- Converted into sentiment/policy stance

Tools: boosting, random forests, DeepAR, etc.
Check e.g. Amazon Chronos 2, or TimesFM 2.5 (Google Research).

Classical macro asks: what mechanism generates the data? **AI forecasting asks**: what pattern helps predict the next observation? Those are complementary questions.

→ Models NOT replaced: AI augments forecasting layer

References: Lenza et al. (2025, *EER*) · Koyuncu et al. (2026, BIS WP) · Alam et al. (2026, FRBSF WP)

Modelling frontier: AI inside Structural Models

Improving the solution: Neural DSGE

- Global nonlinear solutions (beyond perturbation)
- Neural networks approximate policy functions
- Useful in:
    - ZLB
    - crisis regimes

Scaling heterogeneity: HANK + AI

- SSJ → efficient equilibrium computation
- Neural networks approximate distributions

Faster estimation

- Differentiable models (gradients, backprop)
- Neural filters / Hamiltonian Monte Carlo

Richer nonlinear models become numerically feasible without giving up economic discipline.

This frontier is less about "AI replacing economics" and more about making already valuable structural/heterogeneous **models operational at central-bank speed**.

→ Models upgraded: structure remains essential

References: Fernández-Villaverde (2025, NBER WP) · Fernández-Villaverde et al. (2021, ARE) · Auclert et al. (2021, *Econometrica*) · Kase et al. (2025, BIS WP No.1241)

What's next? Beyond Models (Agentic Systems)

From Models to Integrated Systems

LLM-based agents with memory and reasoning

- process narratives
- form expectations
- simulate behaviour

Generative Agent-Based Models (GABM)

Combine:

- forecasting
- structural models
- narrative analysis

AI systems run simulations and narratives

- Risk & scenario analysis
- Shift to '**agentic engineering**'

AI used to integrate data, narratives, and models into a single framework

→ Models become embedded in broader intelligent systems, not just standalone equations

- **Hybrid models (structural + AI + agents)**
- **Explainable AI**

References: Kase et al. (2025, BIS WP No.1312) - Gao et al. (2024, *Nat. HSSC*) · Korinek (2025, NBER WP No.34202)

5

Conclusion

Preparing the future

Key Takeaways

- **The Shift to Scenario Analysis:** Due to high geopolitical uncertainty (e.g., covid, Russian attack to Ukraine, Middle East conflicts), central banks are relying more on scenario-based modeling rather than single baseline forecasts.
- **Resilience over Optimization:** The focus has shifted from finding the “optimal” policy to finding a “robust” policy that holds up under various adverse conditions.
- **AI Integration and cooperation:** Research must incorporate artificial intelligence and big data to improve timeliness and cooperate in interdisciplinary environments.
- **Structural vs. ML Models:** While AI is growing, the demand for structural models – that explain causal relationships and *why* phenomena occur – remains high.

Pressing Modelling questions and topical issues

- How to estimate unobserved, theoretical equilibrium levels of key macroeconomic variables (“star variables”) under a changing world and increased uncertainty
- How to incorporate uncertainty from supply shocks and their interaction with demand-side shocks
- How to incorporate uncertainty from fiscal shocks and interaction with monetary policy
- How to evaluate models and their output, how to evaluate scenario analyses and new frameworks
- How to communicate results to policy makers and general audiences

Important is not just the models but also how and for which purpose you use them

Key structural challenges beside the rapid integration of AI

Labor market polarization

- Skill gaps; Productivity divergence; technological disruption

Aging population and labour constraints

- Labour shortages; Pension insecurity

Geoeconomic Fragmentation and Supply Chain Reconfiguration

- Trade barriers and geopolitical tensions; Aggressive industrial policies; competition for minerals

Climate change and nature degradation

- Increase in price volatility; Transition risks (‘green squeeze’); Disruption of ecosystem services

Persistent inequality

- Wealth concentration and K-shaped economies; Structural barriers (education and techno gaps)

Fiscal fragility

- High debt levels; reduced fiscal buffers

Advices for your career

1. **Think of a fundamental shift in your research journey**. The eras where central bank models relied solely on smooth, historical regularities are behind us. We are operating in an age of geoeconomic fragmentation, unexpected supply shocks, and rapid technological adoption. As the next generation of researchers, your work must not only be **technically rigorous** but also **resilient**.

2. **Embrace Complexity but Prioritize Robustness:** In a world of high uncertainty, complex environments often call for simple decision rules that work well under many different scenarios, rather than highly tuned models that fail when conditions change.

3. **Combine Paradigms with New Data:** As AI and big data reshape our economic landscape, your challenge is to integrate these new technologies with our core structural models. Keep abreast of technological advances for models and infrastructure. Do not fear AI: use it to extract deeper signals from the overwhelming noise, but ensure your models always tell a coherent 'story'.

4. **Expect the Unexpected:** With humbleness, our models must be stress-tested against extreme, yet plausible, scenarios—geopolitical disruptions, climate shocks, or sudden technological shifts.

Your PhD is not just a study of the past; it is the construction of next generation of tools. The goal is no longer just to forecast, but to help policymakers navigate the fog of uncertainty.

We count on you to build and consolidate the new frontier!


THANK YOU
Dziękuję
감사합니다
謝謝
Děkuji
Mulțumesc
Спасибо
Merci
Danke
Köszönöm
Gracias
ありがとう
Kiitos
Obrigado
Terima kasih
Teşekkür ederim
Takk
Dank U
Tack

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