EUROPEAN CENTRAL BANK

EUROSYSTEM

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Econometric modelling at the ECB

15th ECB Central Banking Seminar
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| A | **Modelling challenges in post crisis environment** |

| B | **Addressing the modelling challenges** |

| C | **ECB modelling portfolio for monetary policy preparation: a multi-pronged strategy** |

A	**Modelling challenges in post crisis environment**
B	Addressing the modelling challenges
C	ECB modelling portfolio for monetary policy preparation: a multi-pronged strategy

➢ The financial and sovereign debt crises have posed challenges to the economic and econometric models that had been predominantly used in the economics profession, with the ECB being no exception.

➢ All central banks have been affected by the near absence of financial markets in aggregate models of the economy and the separation between economic and financial econometric models, i.e. the neglect of macro-financial linkages.

➢ Over recent years, there have been substantial modelling efforts at the ECB to adapt or develop models by incorporating:

➢ a variety of financial channels and frictions

➢ more granularity in terms of sectors and agents

➢ multi-country dimension

➢ interactions among a number of policy tools

Macro models at ECB: Uses

Forecasting	Policy Analysis
• Baseline construction: conditioning on a large information set	• Risk and sensitivity analysis (i.e. variants on baseline assumptions)
• Residual/shock analysis: Measuring and identifying contribution of judgement	• Monetary analysis and monetary policy
• Forecast interpretation: developing coherent economic "stories"	• Fiscal policy and structural policy
• Discipline and consistency over time	• Medium term scenarios

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A	**Modelling challenges in post crisis environment**

B	**Addressing the modelling challenges**

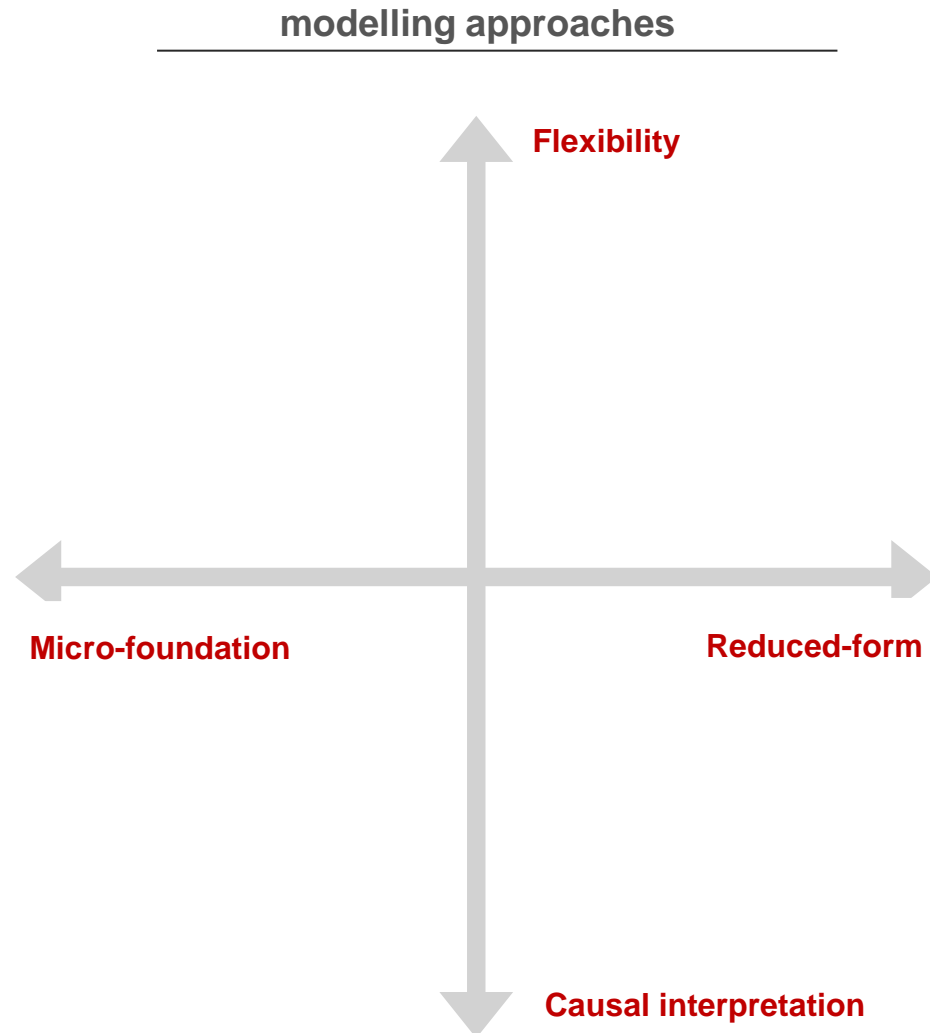| C	**ECB modelling portfolio for monetary policy preparation: a multi-pronged strategy**

- 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 portfolio of **MAIN** model(s) interacting with a range of **SATELLITE** models

- **Modelling strategy: "suite of models"**

  ➢ no best single model: different models have their advantages and disadvantages

  ➢ different models may be best suited to respond to each specific question

  ➢ complementarity and robustness of results

  ➢ possibility of model combination

modelling approaches

Flexibility

Micro-foundation   Reduced-form

Causal interpretation

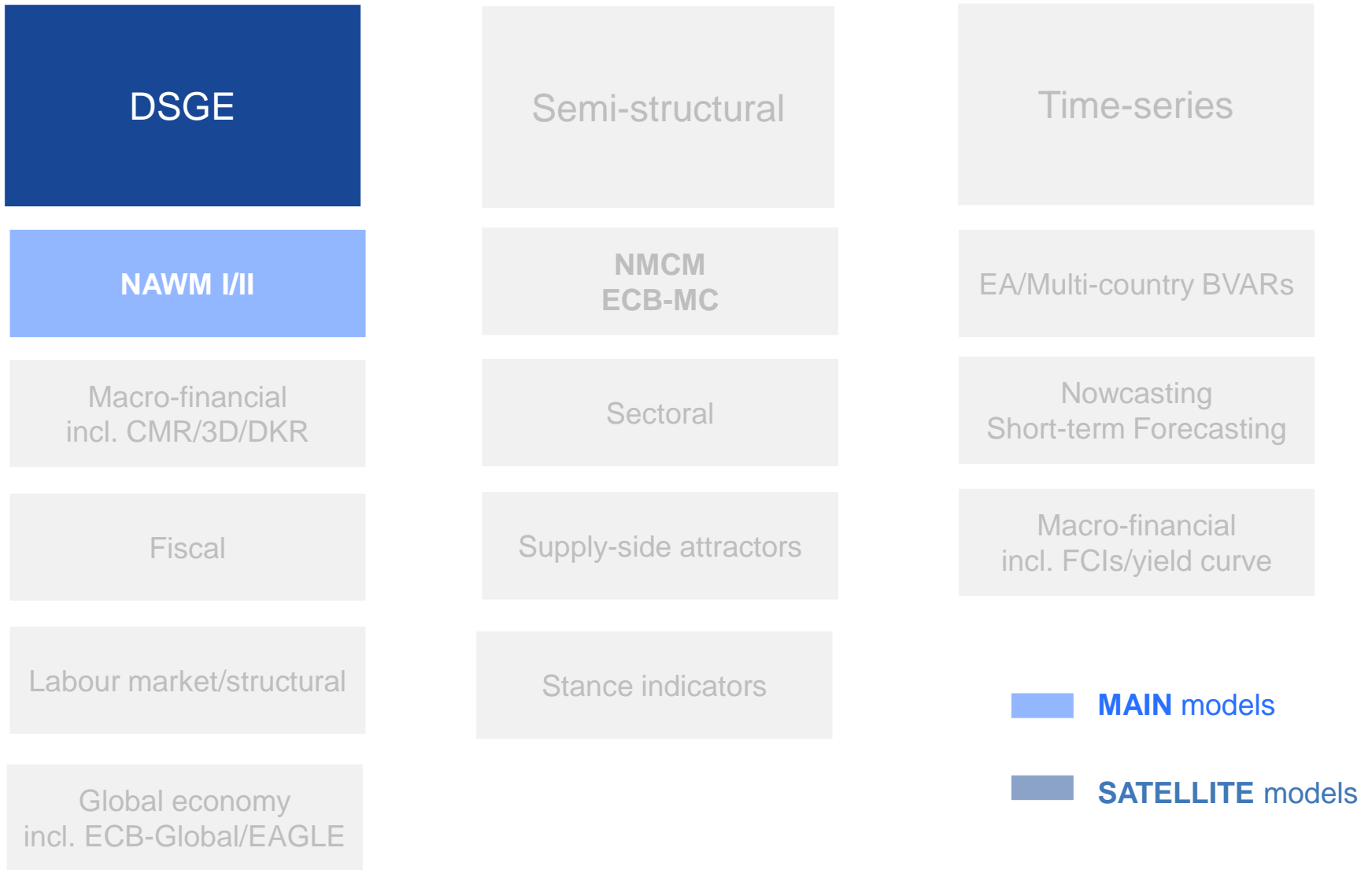| A	Modelling challenges in post crisis environment
B	Addressing the modelling challenges
C	**ECB modelling portfolio for monetary policy preparation: a multi-pronged strategy**

ECB modelling portfolio for monetary policy preparation

DSGE	Semi-structural	Time-series
NAWM I/II	**NMCM ECB-MC**	EA/Multi-country BVARs
Macro-financial incl. CMR/3D/DKR	Sectoral	Nowcasting Short-term Forecasting
Fiscal	Supply-side attractors	Macro-financial incl. FCIs/yield curve
Labour market/structural	Stance indicators	
Global economy incl. ECB-Global/EAGLE		

MAIN models

SATELLITE models

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MAIN models

SATELLITE models

➤ The **New Area-Wide Model (NAWM)** is an open-economy extension of the model by Christiano et al. (JPE, 2005) and Smets-Wouters (JEEA, 2003; AER, 2007) designed for forecasting and policy analysis (cf. ECB WP 944, 2008)

  ➤ **Agents:** households, (intermediate and final-good) firms, monetary authority and fiscal authority

  ➤ **Real and nominal frictions:** habit formation, adjustment costs, sticky prices and wages, limited exchange-rate pass-through

  ➤ **Financial frictions:** domestic and external risk premium

  ➤ Rest-of-World block (SVAR)

  ➤ **Estimated** on time series for 18 key macro variables employing Bayesian inference methods

  ➤ Builds on calibrated, two-country version of NAWM (cf. ECB WP 747, 2007)

➤ In recent years, the ECB's standard monetary policy operations have been complemented by several non-standard measures (NSMs).

➤ Asset price reactions suggest that these NSMs had expansionary effects but the quantitative impact on other macroeconomic variables remains uncertain.

➤ There is a pressing need to facilitate the analysis of the quantitative effects of NSMs by developing coherent structural macroeconomic modelling frameworks.

➤ Standard DSGE models are silent on the transmission channels of NSMs or, more generally, on the role of financial frictions and the propagation of financial disturbances.

The financial extension of the NAWM: A bird's eye

➢ Households face a loan-in-advance (LIA) constraint:

  ➢ households accumulate physical capital, the services of which they rent out to firms

  ➢ capital investments have to be financed by new bank loans (Carlstrom- Fuerst- Paustian, 2014)

➢ Financial intermediaries (banks) engage in maturity transformation:

  ➢ banks offer long-term loans to the private sector to finance capital investments and hold domestic and foreign long-term government bonds

  ➢ banks' long-term assets are modelled as nominal consoles with geometrically decaying coupons à la Woodford (2001)

  ➢ banks fund their assets with short-term household deposits and with their equity/net worth (accumulated through retained earnings)

➢ Firms' foreign trade is intermediated by banks.

NAWM II: a bird's eye view

Imperfect financial markets:

- ➢ the option to abscond (agency problem) limits the leverage of banks (Gertler-Karadi, 2011 and 2013)

- ➢ banks' capital position influences the transmission of shocks (financial accelerator mechanism)

➢ Delayed pass-through to lending rates:

- ➢ loans are originated by funding-constraint wholesale banks

- ➢ monopolistically competitive retail banks (Gerali-et-al., 2011) distribute loans and adjust loan rates sluggishly

➢ Exogenous financial disturbances:

- ➢ shock to survival rate of wholesale banks (net worth)

- ➢ shock to mark-down parameter of retail banks (market power)

NAWM II: a bird's eye view

➢ Central bank can purchase long-term private sector loans and/or government bonds:

  ➢ relief of banks' balance sheets/leverage constraints (stealth recapitalisation) and improvement of lending conditions

  ➢ banks' holdings of foreign currency-denominated bonds accounts for exchange-rate channel of asset purchases

➢ Households face portfolio adjustment costs w.r.t. their holdings of government bonds.

➢ Model is estimated on quarterly data (1985 to 2014)

  ➢ 18 macro time series (NAWM I)

  ➢ Financial: AAA ten year government bond for US and EA,

  ➢ Survey data on long-term inflation expectations and long term growth expectations and measure of output gap
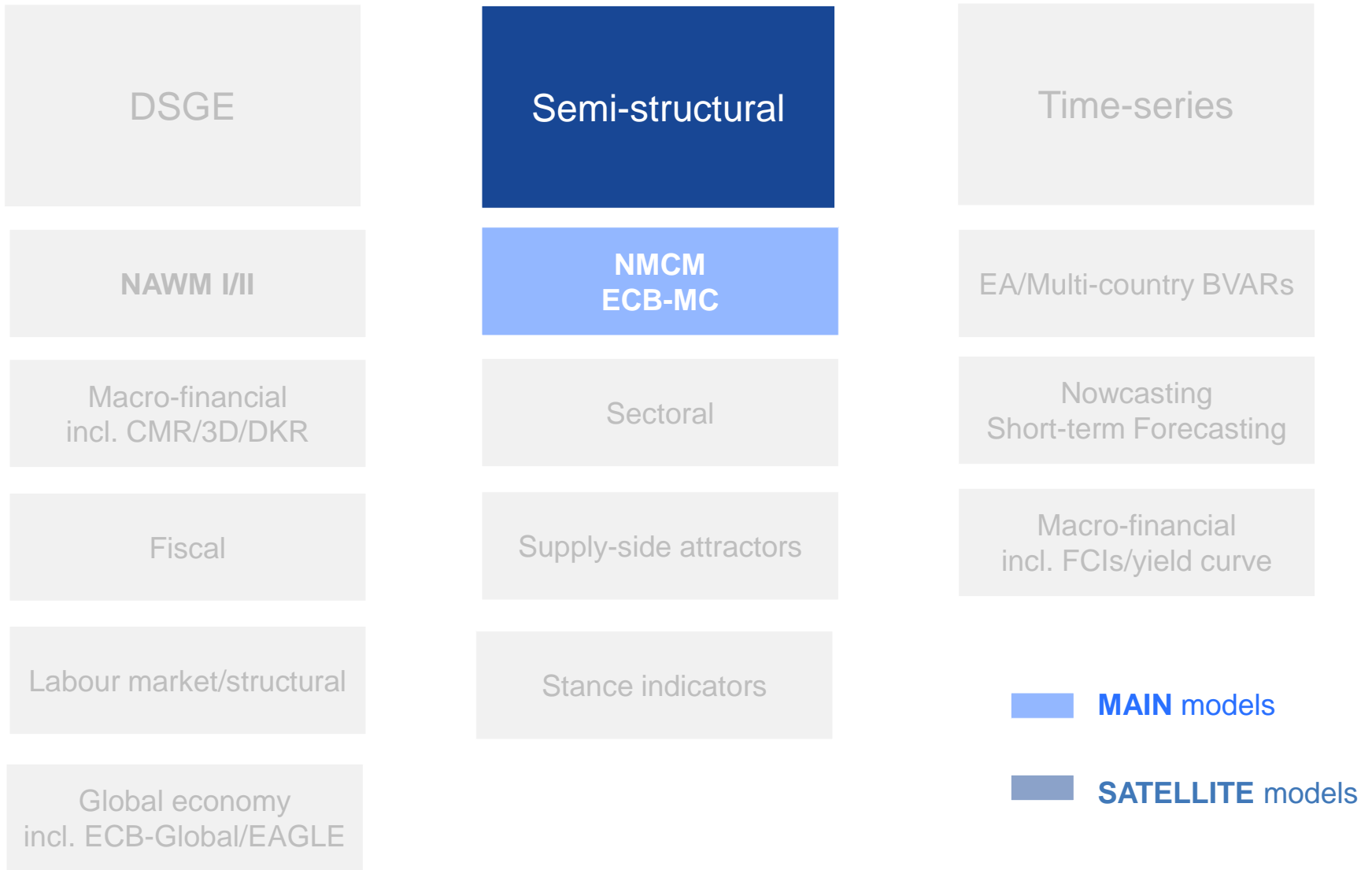
➢ Simulating the effects of asset purchases

    ➢ Asset Purchase Programme (APP) as announced in January 2015:

    ➢ 11% of GDP, 8-year maturity (9% in ten-year equivalents)

    ➢ 20% AAA government bonds, 80% risky assets

    ➢ hump-shaped, peaks in 2 years' time, exits as bonds mature

➢ Alternative calibration:

    ➢ higher fraction of AAA government bonds: 70% (vs. 20%) Central bank can purchase long-term private sector loans and/or government bonds:

NAWM II: Simulating the effects of asset purchases
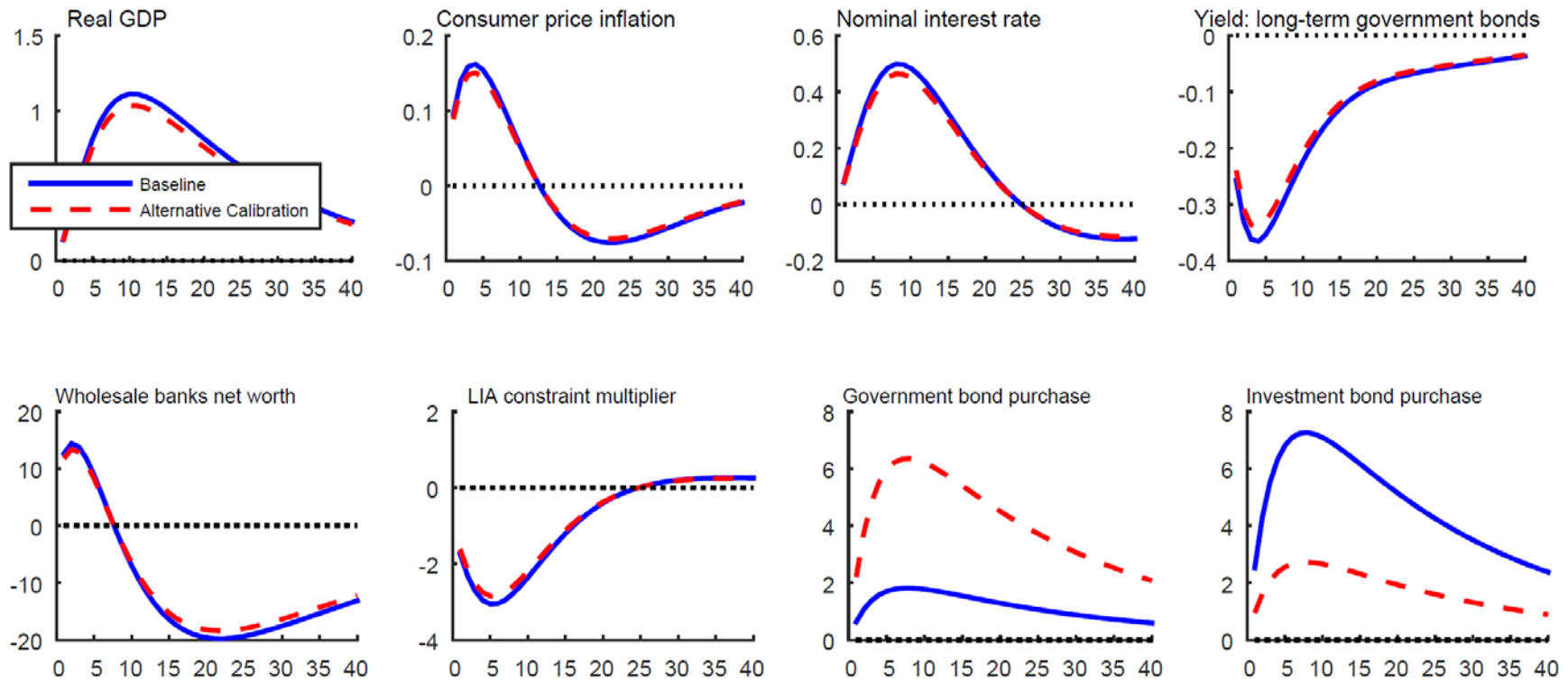
Note: This slide depicts the impulse responses of selected domestic variables to an asset purchase shock for the baseline and an alternative calibration. All impulse responses are reported as percentage deviations from the model's non-stochastic balanced growth path, except for the impulse responses of the inflation and interest rates which are reported as annualised percentage-point deviations.
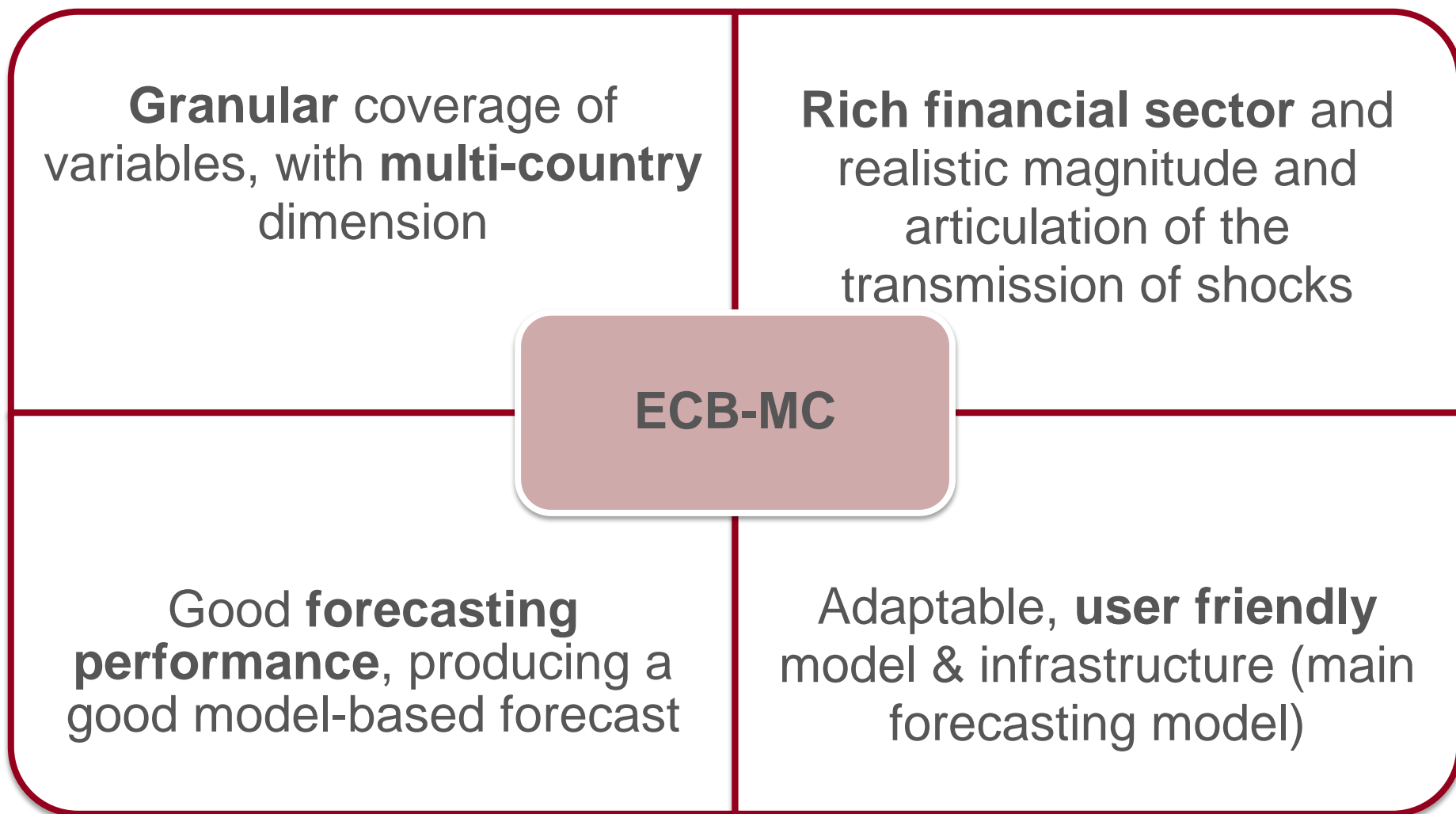
ECB modelling portfolio for monetary policy preparation

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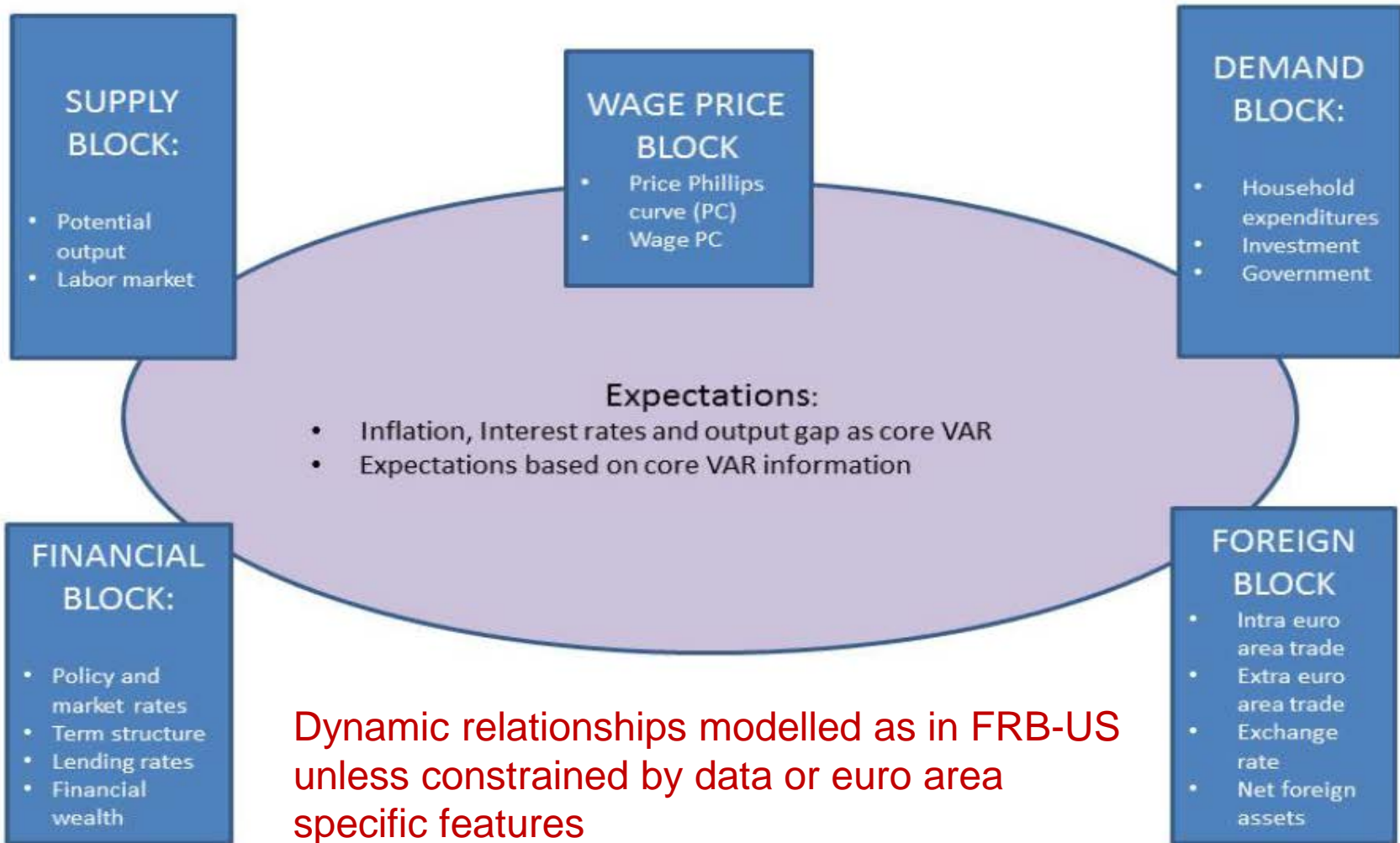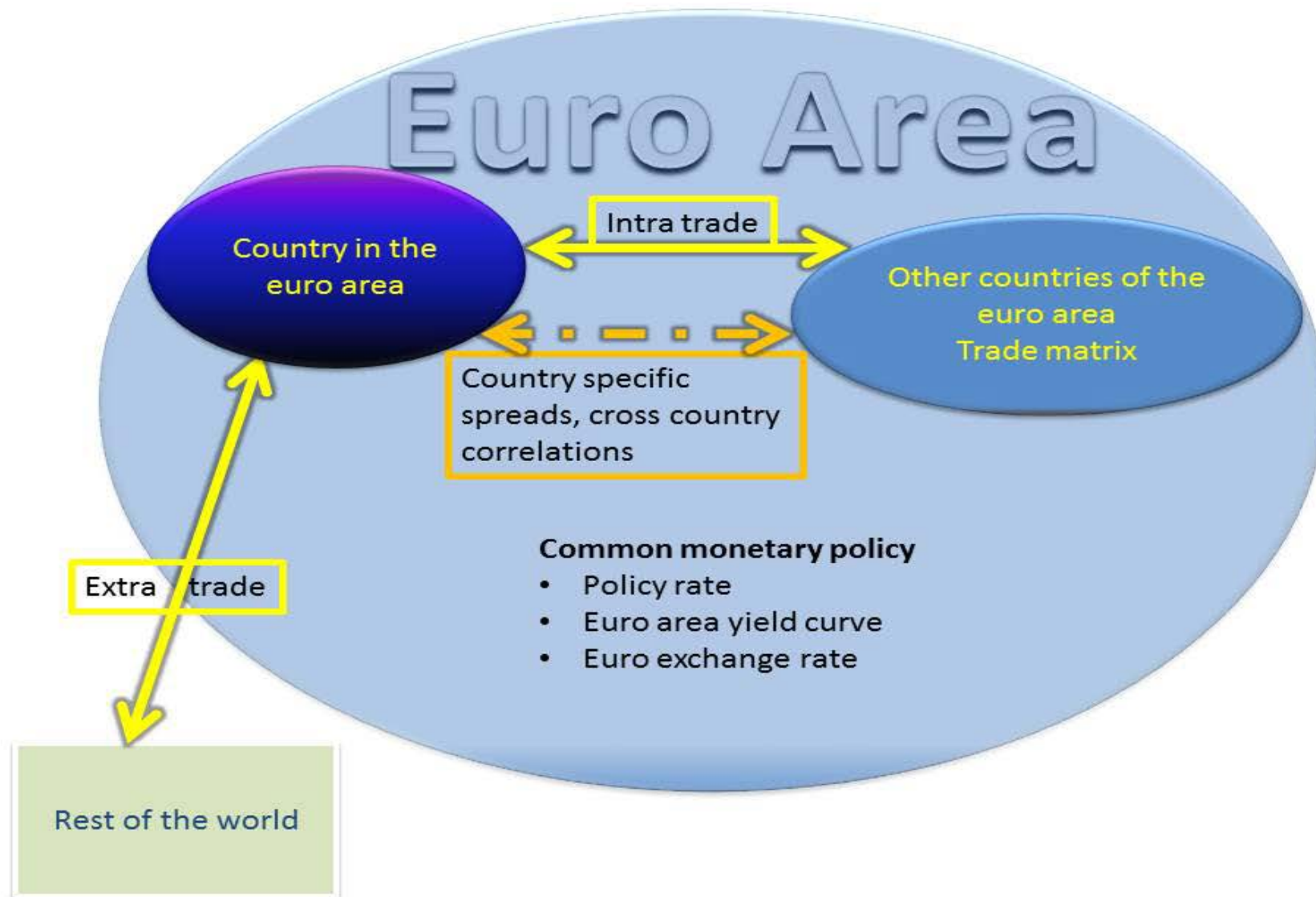**MAIN** models

SATELLITE models

- The NMCM is a multi-country model, with five country blocks (DE, ES, FR, and NL) linked via trade, common monetary policy and common exchange rate

- The institutional framework of the ECB's forecasting process:

    - bottom-up approach: **individual country forecasts**

    - ECB (Mar. and Sept.) and NCB staff (Jun. and Dec)

    - forecasts conditional on technical assumptions based on satellite models

    - judgmental forecasts

- The financial and sovereign debt crises further revealed the importance of the **country dimension** and the benefits of **flexible semi-structural models**.

- In response to the crises, the existing NMCM was re-estimated and partly ad-apted, before a decision was taken to more fundamentally revamp the ECB's multi-country modelling.

➢ The main goals in developing a new version of the multi-country model:

  ➢ taking into account the **multi-country dimension**, also on the financial side

  ➢ accounting for **multiple channels** of monetary policy transmission and featuring a realistic magnitude and articulation of the transmission of shocks

  ➢ good **forecasting performance**

  ➢ adaptable **user-friendly** model & infrastructure (main forecasting model)

➢ A semi-structural approach along the lines of FRB-US:

  ➢ **theory-based** but **less stringent** than a DSGE model

  ➢ **good empirical fit**, with empirical regularities matched in a reliable way

  ➢ **flexible framework**: more granularity in the coverage of variables; more straight-forward to include multi-country dimension; easier to link with other in-house tools, new mechanism can be introduced more swiftly

➢ ECB-MC has a flexible empirical orientation, inspired by the FRB-US model

Granular coverage of variables, with **multi-country** dimension

Rich financial sector and realistic magnitude and articulation of the transmission of shocks

ECB-MC

Good **forecasting performance**, producing a good model-based forecast

Adaptable, **user friendly** model & infrastructure (main forecasting model)

SUPPLY BLOCK:
- Potential output
- Labor market

WAGE PRICE BLOCK
- Price Phillips curve (PC)
- Wage PC

DEMAND BLOCK:
- Household expenditures
- Investment
- Government

Expectations:
- Inflation, Interest rates and output gap as core VAR
- Expectations based on core VAR information

FINANCIAL BLOCK:
- Policy and market rates
- Term structure
- Lending rates
- Financial wealth

FOREIGN BLOCK
- Intra euro area trade
- Extra euro area trade
- Exchange rate
- Net foreign assets

Dynamic relationships modelled as in FRB-US unless constrained by data or euro area specific features

The revamp of multi-country modelling

➢ The Great Recession in Euro Area offered few lessons:

  ➢ **Multi-country dimension** of Euro Area is important

  ➢ Macroeconomic models have to include a **richer financial propagation** mechanism

  ➢ Models should be **readily adaptable** in order to address newly emerging policy questions in a timely manner

➢ In response ECB decided for a revamp of its multi-country modelling

  ➢ The main forecasting model redesigned along the lines of the Federal Reserve's **FRB/US model** that proved invaluable tool at FED during the crisis

  ➢ Development of purely statistical Bayesian VAR model to validate more structural models and to cross-check projections

- **Financial frictions**
  - Allows for a much richer set of financial variables, including a variety of spreads (risk, term, sovereign)

  - Empirical approach without taking a stance on the exact theoretical mechanism. Financial frictions, like different pass-through to lending rates, captured empirically

- **Rational expectations**
  - Baseline assumes bounded rationality by agents: VARs with market/survey based expectations.

  - Allows for Model Consistent expectation or mix, and also other expectation formations, like learning

- **Heterogenous agents**
  - Derivation of consumption function takes into account rule of thumb consumers and different consumption elasticities for different population cohorts
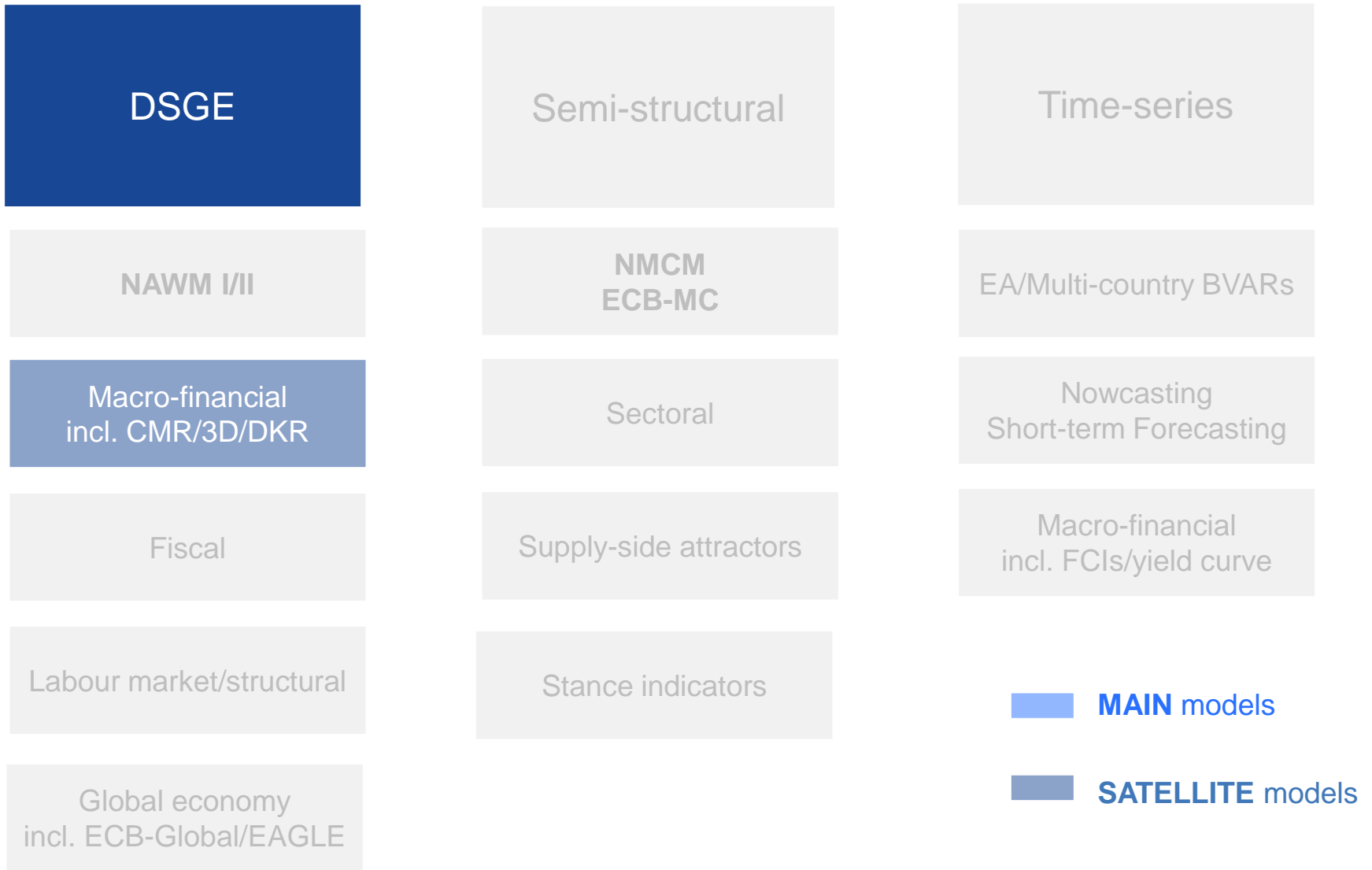
- **Microfoundations**
  - "Targets" microfounded and constructed/estimated from the data – empirical check of the theory

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SATELLITE models
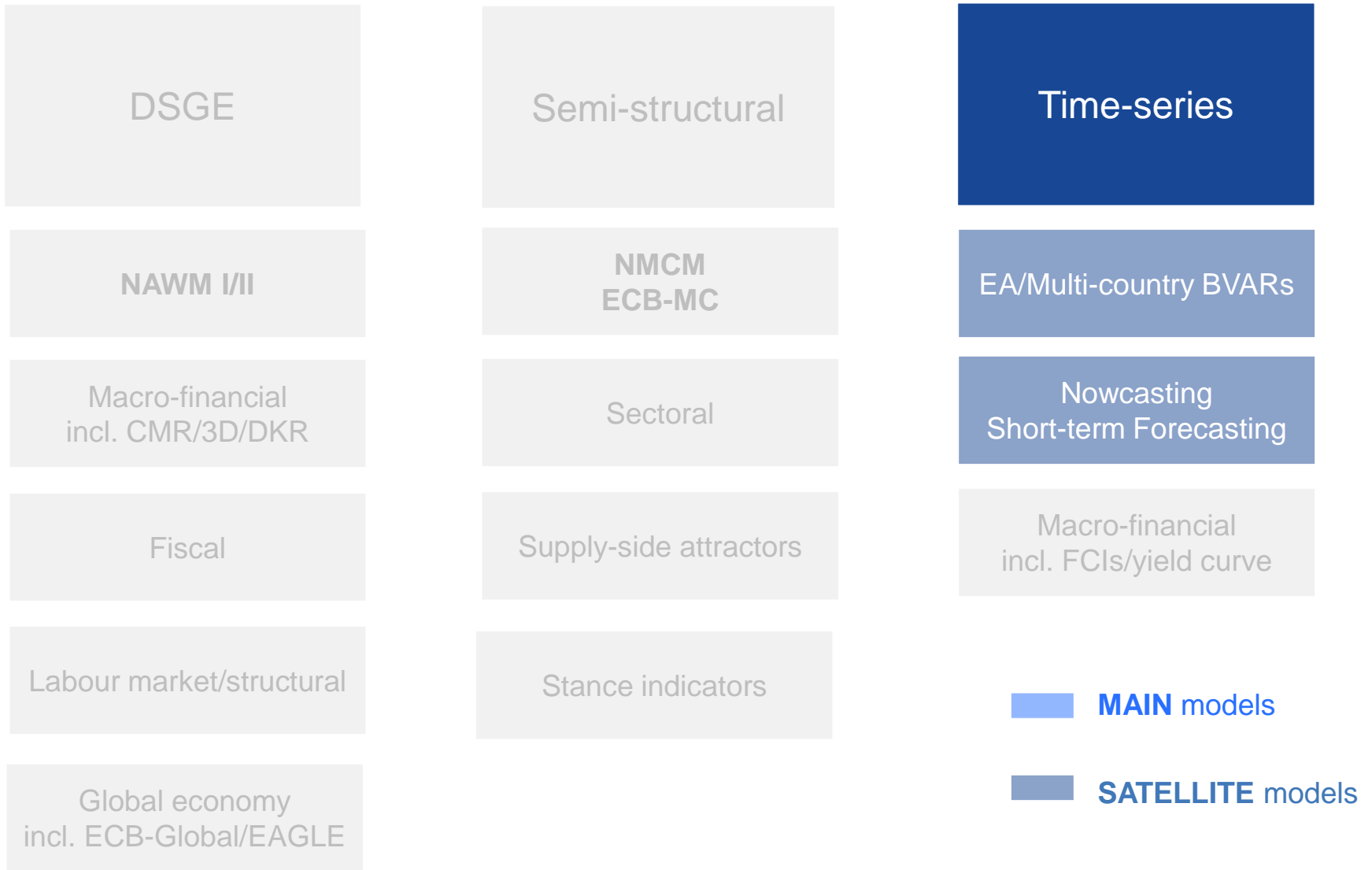
➢ Enhance the suite of time-series models for the euro area and for the large euro area countries:

  ➢ BVARs for cross-checking the official economic projections along selected conditional dimensions

  ➢ providing time-series benchmarks on sectoral and cross-country regularities for the semi-structural models (ECB-MC)

  ➢ nowcasting and short-term forecasting frameworks

➢ Enrich the suite of models by incorporating transmission channels to assess the impact of non-standard monetary policy measures NSMs:

  ➢ refining and broadening the set of identification strategies for NSMs in (B)VAR analysis

➢ Account for non-linearity in macroeconomic propagation as well as uncertainty in long-term attractors :

  ➢ non-linear/TVP time-series framework for sectoral and risks analysis

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MAIN models

SATELLITE models

➢ Estimated/calibrated models with both **demand and supply-side credit frictions**, based on "first principles" in macro but major deviations from pre-crisis paradigm:

  ➢ bank capital channel, incentives for excessive credit and regulatory constraints

  ➢ sovereign-banking nexus and funding access of banks

  ➢ credit frictions for both households and firms

  ➢ default as a credible characterization of financial instability, not only for banks but also non-financial corporations and households ("3D")

  ➢ both for euro area and multi-country settings

➢ Those models can provide a monetary policy perspective on **regulatory, supervisory and macroprudential** interventions

  ➢ transitional costs of higher bank capital ratios through the euro area: Bank deleveraging process which adversely constrained the provision of credit

  ➢ long-term cost and benefits of capital regulation:

    ➢ risk-sensitivity of bank liabilities

    ➢ fiscal consequences of bank fragility

  ➢ strategic complementarities between MP and MaPru (capital versus asset based, untargeted versus targeted)

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Forward Guidance in DSGE models

DSGE models are, in equal measure, _ideal_ and _problematic_ for studying forward guidance (FG)

➤ FG on policy rates is a policy tool that many central banks have successfully used.

➤ FG relies on influencing the expectations of private sector agents.

➤ DSGE models, populated with forward looking, intertemporally optimising agents, are an **_ideal_** laboratory to study the macroeconomic impact of FG.

➤ However, standard DSGE models suggest that forward guidance effects on output and inflation grow at an accelerating rate with the length of the horizon making this a **_problematic_** approach.

Plan: Present a roadmap for reconciling DSGE experiments and empirical evidence.

Consumption Euler equation:

$$c_t = E_t c_{t+1} - \sigma(r_t - E_t \pi_{t+1})$$

Solving the Euler equation forward yields

$$c_t = -\sigma E_t \sum_{j=0}^{\infty} \left(r_{t+j} - \pi_{t+j+1}\right)$$

➢ Private consumption is governed by the consumption Euler equation, which can be written as the undiscounted sum of future real rates.

➢ News about future interest rates — at *any* horizon — has the same (partial equilibrium) effect on current consumption.

➢ The farther out the rate drop, the longer the consumption boom lasts.

➢ This feature is labelled the '*forward guidance puzzle*'

- A number of model properties imply that the quantitative impact of FG is increasing in the horizon:

  - Perfect information: fully informed and attentive, rational agents
  - Representative agent: complete risk insurance, infinite planning horizon
  - Stylized financial side: complete interest rate pass-through

- Focus on two approaches

  - *Discounting*: many proposals to fix the FG puzzle can be subsumed as 'discounting' in Euler equation.

  - *Imperfect credibility (IC)*: introduction of a fraction of agents ignoring or not being attentive to central bank announcements.

- Discounting requires modifications of the equilibrium conditions of the model, thus changing the transmission mechanisms. IC only impacts the simulated scenario.

Discounted consumption Euler equation:

$$c_t = \alpha E_t c_{t+1} - \sigma(r_t - E_t \pi_{t+1})$$

Solving the Euler equation forward now yields

$$c_t = -\sigma E_t \sum_{j=0}^{\infty} \alpha^j (r_{t+j} - \pi_{t+j+1})$$

➢ In a typical DSGE model, $\alpha = 1$. The Euler equation, which governs how households smooth consumption over time in response to changes in real interest rates, features no discounting of expected consumption.

➢ $\alpha < 1$ is a reduced form approach to capture a host of relevant factors: uninsurable income risk, borrowing constraints, overlapping generations, and informational frictions.

➢ Near-term interest rate changes have larger (partial equilibrium) effects than far-term changes.

➢ Follows the approach of McKay et al. (2017)

<u>Expectations under imperfect credibility</u>:

$$E_t R_{t+1} = (1 - \lambda) E_t R^{FG}_{t+1} + \lambda E_t R^{TR}_{t+1},$$

where

- R^{FG}_{t+1} is the announced FG path

- R^{TR}_{t+1} is the policy rate that would prevail under the Taylor rule

➢ A fraction λ of the agents are inattentive to the FG announcement, and expect the central bank to act according to the Taylor rule.

➢ Possibility to model a decaying share of attentive agents for FG promises further out in the future.

➢ Follows approach by Coenen and Wieland (2004).

Consumer price inflation
(cumulated annual rates)
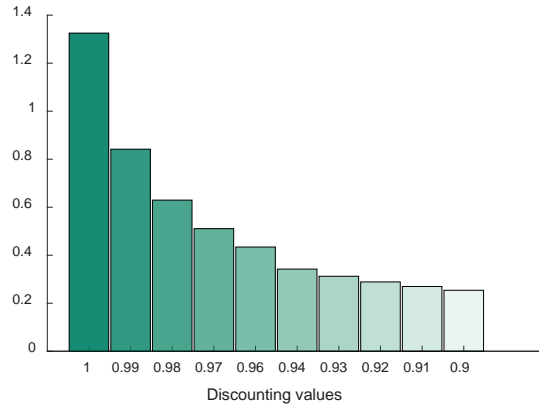
Real GDP growth
(cumulated annual rates)

Discounting à la McKay et al. (2017)
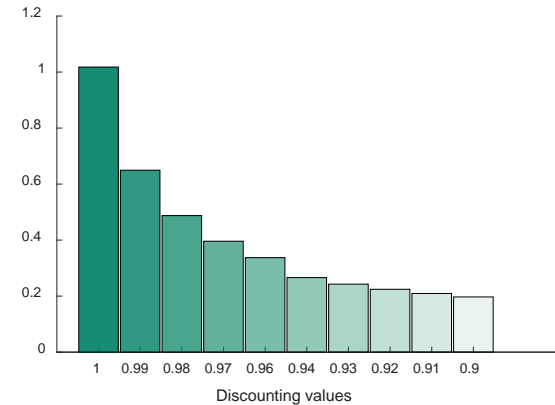
Imperfect credibility à la Coenen and Wieland (2004)
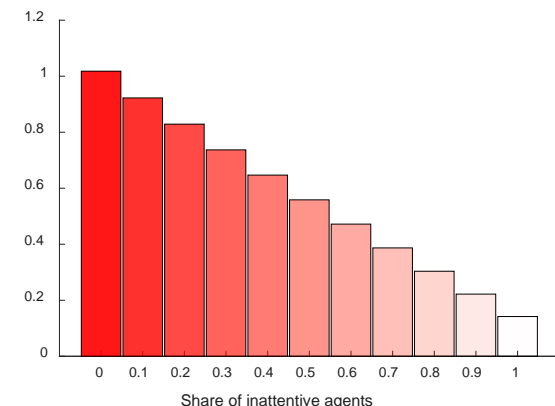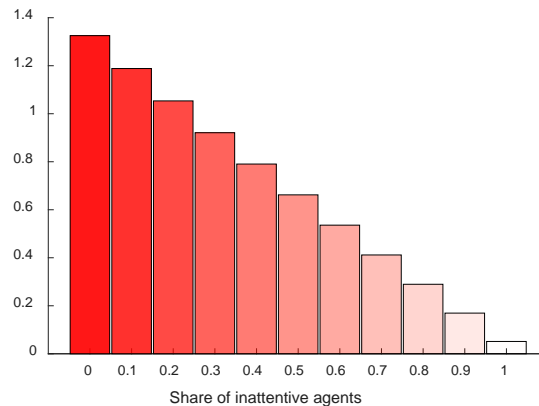
Note: Counterfactual simulations based on the NAWM. The bars depict the cumulative effects on consumer price inflation and real GDP growth over the March 2018 MPE horizon of the counterfactual with additional 3-quarter rate forward guidance (FG). Discounting à la McKay et al. (2017) and imperfect credibility similar to Coenen and Wieland (2004).

Attempt to shrink the parameter uncertainty with use of VAR evidence

Parsimonious, forecast data-augmented, VAR with variables:

$$x_t = \begin{bmatrix} \text{\color{red}SPF h−quarter ahead} \\ \text{\color{red}interest rate forecast } (\color{red}Rh) \\ \vdots \\ \text{Short−term interest rate } (R) \\ \text{Real GDP } (y) \\ \text{Consumer price index } (\pi) \end{bmatrix}$$

Structural shocks identified with sign and zero restrictions:

|	FG shock	MP shock
Rh	$(-)$	.
R	$(0) \times h, (-)$	$(-)$
y	$(+)$	$(+)$
π	$(+)$	$(+)$

Note: Quarterly data from 2002q1 to 2017q2. Short-term interest rate is the ECB's MRO. This matches the interest rate SPF participants are asked to forecast. Consumer price index is the HICP. Real GDP is per capita.

➢ Much of the empirical evidence on the effect of FG is not in an amenable form for parameterizing DSGE models.

➢ While VARs are not suited to counterfactual FG experiments, they can be used to calibrate the parameters that govern the power of FG in DSGE models.

➢ Alternative approaches are calibration of deep structural parameters or full re-estimation of the model with forecast variables. Identification issues make the latter difficult.

➢ DSGE model is calibrated to match IRF from VAR.

Building confidence on the VAR identification

Output gap

> ➢ We simulated data from a canonical 3-equation New-Keynesian model augmented with FG shocks.

> ➢ We then estimated the proposed VAR with sign restrictions using the simulated data.

> ➢ Conclude that the identifying assumption do a reasonable job of recovering the true responses to h-quarter ahead forward guidance shocks
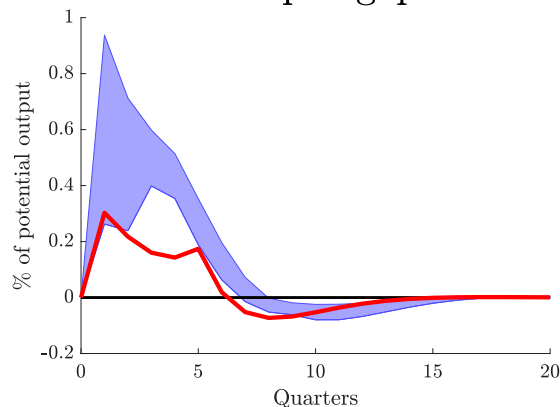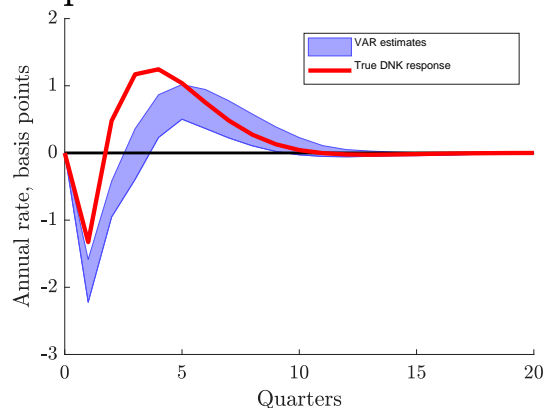
Consumer price inflation
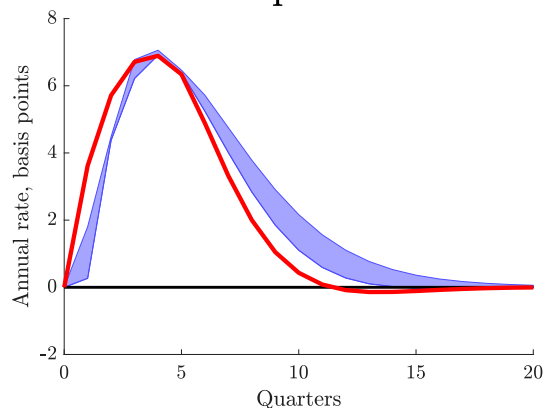
4q ahead interest rate forecast

Note: 10,000 quarters of simulated data from the 3-equation NK model in Carlstrom et al. (2012). The model is augmented with anticipated monetary policy shocks at 1-4 quarters ahead. Forecast data are the model's rational expectations forecasts. Purple: 86 percent credible set from estimated VAR. VAR includes the Short-term interest rate (R), 1-q to 4-q ahead R forecast (Rh), Consumer price inflation, and the Output gap. Christoffel, de Groot, Mazelis, Montes-Galdon (2018).

Developments on Econometric Modelling at ECB after Crisis

➢ Development of new DSGE with financial sector (NAWM II)

➢ Development of multicountry model with financial sector and new approach on granularity and system properties

➢ Development of tools to increase scope of analysis (Non-linearities around ELB, asset purchases, forward guidance, …)

Still challenges ahead to academic developments into policy process:

➢ Heterogeneous agent models (agent based models)

➢ Accounting for non-linearities in a broader context

➢ Big data

➢ …